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PROGRESS SUMMARY NO. I

MECHANICAL PROPERTIES OF FLUSH-RIVETED JOINTS

SUBMITTED BY FIVE AIRPLANE MANUFACTURERS

By William Charles Brueggeman
National Bureau of Standards

NACA

WASHINGTON

W-79

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MECHANICAL PROPERTIES OF FLUSH-RIVETED JOINTS SUBMITTED BY FIVE AIRPLANE MANUFACTURERS

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INTRODUCTION

Information on flush-riveted joints for aircraft construction is greatly needed in the present emergency. The National Bureau of Standards is investigating the mechanical properties of flush-riveted joints at the request of the National Advisory Committee for Aeronautics and with the cooperation of the Air Corps, War Department; the Bureau of Aeronautics, Navy Department; and the Civil Aeronautics Administration, Department of Commerce.

From tests on a series of standardized specimens obtained from a number of airplane manufacturers, the strength, occurrence of defects, and effect of the angle of the rivet head have been determined. The specimens represent combinations of structural memobers frequently joined by flush rivets and were designed to afford a comparison between the different types of rivet and riveting process.

The present program contemplates tests on series of specimens from 15 manufacturers of which 5 series have been completed and are reported herein. As soon as tests were completed on each series the results have been made available in the form of a progress report to governmental agencies and to the manufacturer. After all the specimens are tested it is expected that a report summarizing the results and comparing in detail the several types of joints will be published. However, due to the immediate need for this information, the results will be released from time to time in the form of a progress summary.

SPECIMENS

The specimens complied with "Specification for Flush-Riveted Test Specimens, Second Series," which was prepared by the National Bureau of Standards for this investigation. Shearing and tensile specimens types I to VI are shown in figure 1; specimens VII, VIII, and IX are exhibit specimens showing constructional details of the joints; specimens X and XI contain a sufficient number of rivets to determine the frequency of cracks and consist of a pair of dimpled sheets joined by 50 flush rivets as follows:

Specimen	Sheet thickness (in.)	Rivet diameter (in.)
X	0.025	1/8
XI	.064	3/16

The manufacturers' names are not given but the manufacturer and his specimens are designated by the number of the progress report in which the results were given. Manufacturer 1 and 5 are the same; the two numbers refer to his countersunk (the term "countersunk" refers to the sheet adjacent to the manufactured head of the rivet) and dimpled specimens, respectively, which were reported separately. Thus there were 5 manufacturers and 6 reports.

The rivets were the following:

Report	Head			Alloy**
	Angle (deg.)	diameter* / d	depth* / d	
1 and 5	115	2.05	0.37	A17S-T and 24S-T
2	78	1.60	.37	A17S-T
3	115	1.60	.29	A17S-T
4	78	1.60	.37	A17S-T and 17S-T
6	100	1.83	.37	A17S-T and 24S-T

*d = nominal shank diameter. In some cases the head proportions varied slightly for some sizes; the value given is approximately the average.

**As stated by the manufacturer.

Each manufacturer stated that the sheet alloy was alclad 24S-T except that manufacturer 4 stated that the alloy for his specimens was 24S-T. Shearing tests of the rivets and tensile tests of the sheet were made by the National Bureau of Standards to determine compliance with Army or Navy specifications. The shearing and tensile properties, respectively, complied with the requirements of an Army or Navy specification for the material as described by the manufacturer.

From the manufacturer's description of the riveting process it is believed that the sheets were separately dimpled in all cases. Generally the male dimpling tool for the surface sheet had an included angle about equal to that of the rivet head, but the female had a greater angle. Both had a greater angle for the sheet underneath the surface sheet; this underneath sheet was countersunk in the type-IV specimens of report 6. A few of the rivet holes showed evidence of being reamed after dimpling, probably for the purpose of alinement. Most of the holes were burred. Rivets were driven by squeezing, one-shot impact, or repeated impact. Tool drawings submitted by manufacturers 2 and 4 showed similar dimpling tools and similar constructional practices.

TESTS

Tensile loads were applied to the shearing specimens to cause shearing and bearing loads on the rivets. The slippage was determined on at least one shearing specimen of each kind by applying a load, unloading to almost zero, measuring the slippage, applying a greater load, etc. The slippage was measured by scribing a line with a razor blade on the edges of the overlapping sheets opposite a rivet and measuring the offset in this line by means of a Brinell microscope (fig. 2). The offset was measured for each load after that load had been applied and released to almost zero. Offsets measured on both edges of the specimen were averaged. Generally the maximum load was determined on three shearing specimens of each kind.

The tensile specimens were attached to the testing machine as shown in figure 2 and the breaking load was determined. Three or four specimens of each kind were tested.

Specimens VII, VIII, IX, and in some cases shearing specimens representing several combinations of d and t were sectioned for examination to determine the construction and the occurrence of defects. The rivets of specimens X and XI were drilled out and the sheets were examined for cracks.

RESULTS

Load-slippage curves were plotted for all shearing specimens on which slippage was determined. Nominal shearing and bearing stresses corresponding to slippages of 0.01d, 0.03d, and 0.05d for some manufacturers, 0.01d, 0.05d, and 0.10d for others, were determined from these curves and plotted in figures 3, 4, 5, and 6. In these figures the coordinate axes are the shearing stress S_s and the bearing stress S_b. A circumferential scale of d/t determined by eliminating load from the relationships

$$\text{load} = \frac{\pi d^2}{4} S_s = dtS_b \text{ for types I and III}$$

$$\text{load} = 2\frac{\pi d^2}{4} S_s = 2dtS_b \text{ for types II and IV}$$

is also shown on the graphs. The hollow characters (circle, triangle, or square) on a radial line indicate the stresses corresponding to the three slippages for one specimen whose d/t ratio corresponds to that line. The maximum stresses for this specimen are indicated by a solid character. Other solid characters on or near the radial line are the maximum stresses for additional shearing specimens of the same kind. In computing stresses and d/t ratio the nominal rivet diameter d and the measured sheet thickness t as shown in figure 1 were used. Where the joint contained two sheets of the same nominal thickness but different measured thickness, the measured thickness of both was averaged.

The tensile strength was computed for the tensile specimens by dividing the breaking load by the nominal cross-sectional area of the rivet. The results are given in figures 7 and 8.

Photomacrographs of the sectioned specimens are shown in figures 9 to 11 and 13 to 15. Figure 12 shows radial cracks in report-2 specimens.

For the purpose of comparison, the manufacturers are listed below in the sequence of decreasing shearing and bearing stress at a given slippage or at failure. (No. 1 of the sequence showed the greatest stresses at a given slippage or at failure.)

The sequence was determined by the magnitude of the stresses over a range of d/t at which a given slippage or failure occurred. In some cases it was difficult to determine the sequence due to the scatter of the points and to the fact that the sequence frequently varied with the d/t ratio. In these cases the assigned sequence depends on personal judgment. Where several report numbers are underlined the results are judged to be about equal.

In comparing the specimens it is necessary to evaluate the effect of the rivet alloy. All of the manufacturers used A17S-T rivets, but manufacturers 4, 5, and 6 used stronger alloys in addition for some specimens, particularly in the 3/16-inch and 1/4-inch diameters. The graphs for manufacturer 6 suggest that the use of 24S-T for the lower d/t ratios where the specimens are critical in shearing would improve the slippage and the strength. In report 4,17S-T-riveted specimens ($d/t = 3.1$) had less slippage and greater strength than comparable specimens employing A17S-T rivets. Report 5 shows little effect of the rivet alloy.

The table shows that, in general, report-6 dimpled specimens had the least slippage for types I and II, report-4 for types III and IV; one or the other of reports 4 and 6 showed the greatest breaking strength for the four types. Reports 2 and 3 showed the least slippage for countersunk specimens. The breaking strength of report-5 dimpled tensile specimens was the greatest. Thus no report showed superiority for all types of specimen.

Figure 9 shows, at the lower right, a joint in which the countersunk head extends practically through the second sheet. This condition is believed to be conducive to slippage where the head angle is as great as 115° and to facilitate lapping of the upset shank over the root of the manufactured head.

Generally the conformance of the sheets to each other and to the rivet at the dimple is believed to be good and there were few obvious defects, such as clearances, cracks, voids, etc., which would explain differences in behavior. Angular clearance in some machine-countersunk specimens is evident in figure 9 where manufacturer 1 used a 120° countersink of his 115° rivet. Occasional slight clearance of a dimpled sheet in the machine-countersunk backing member may be seen in sectioned specimens for several manufacturers.

Radial cracks were found only in specimens X and XI of report 2 as shown in figure 12. These occurred in one or the other sheet or both at 8 percent of the rivet holes in specimen X and 62 percent of the holes in specimen XI. Most of the cracks were quite small but a few extended almost to the rim of the dimple. No circumferential cracks were found.

National Bureau of Standards,
Washington, D. C., January 16, 1942.

TABLE

SEQUENCE OF REPORT NUMBERS FOR DECREASING STRESS CORRESPONDING TO A GIVEN SLIPPAGE

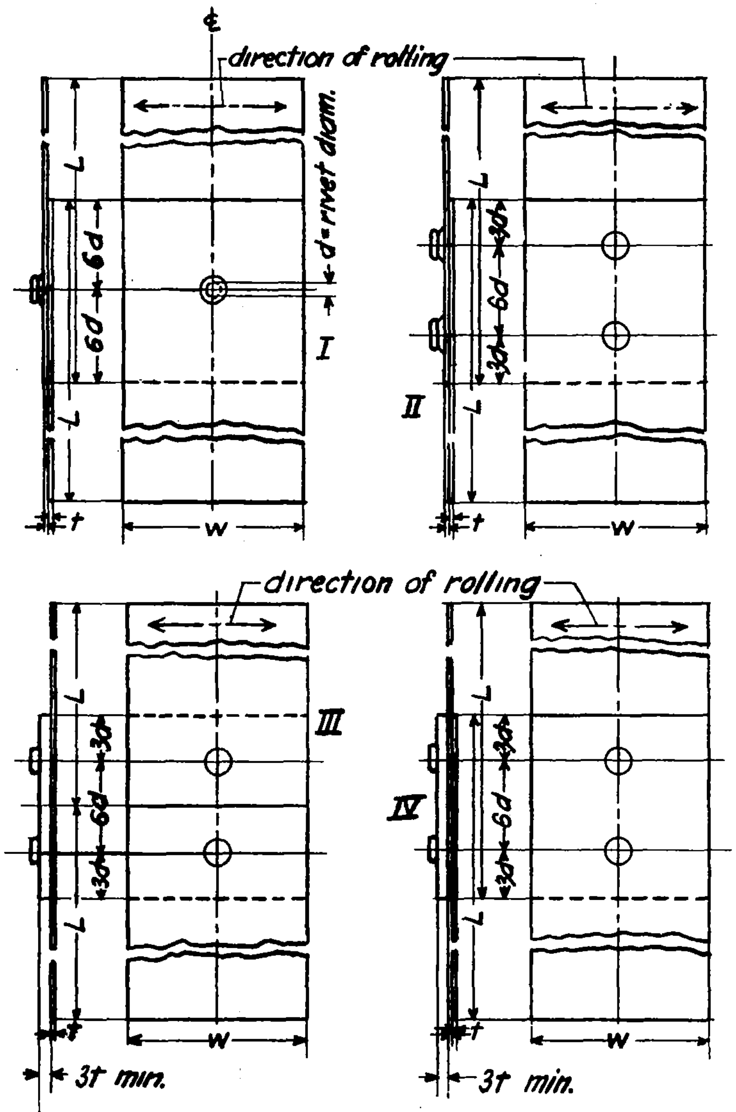
	Dimpled Sequence					Countersunk* Sequence		
Type	1	2	3	4	5	1	2	3
Slippage = 0.01d								
I	2	5	-	-	-	3	2	1
II	6	2	5	3	4	2	3	1
III	-	-	-	-	-	2	3	**
IV	2	4	3	5	6	3	2	**
Slippage = .05d								
I	6	2	5	4	3	3	2	1
II	6	2	5	4	3	2	5	3
III	4	2	3	6	5	2	3	**
IV	4	2	3	5	6	3	2	**
Slippage = .10d								
I	6	4	5					
II	6	5	4					
III	4	6	5					
IV	4	5	6					
Sequence for decreasing shearing strength								
I	6	2	4	5	3	1	2	3
II	6	5	2	4	3	2	1	3
III	6	4	5	2	3	2	3	**
IV	4	5	6	2	3	2	3	**
Sequence for decreasing tensile strength								
V	5	6	3	2	#	3	2	
VI	5	6	3	2	#	3	2	

*A17S-T rivets.

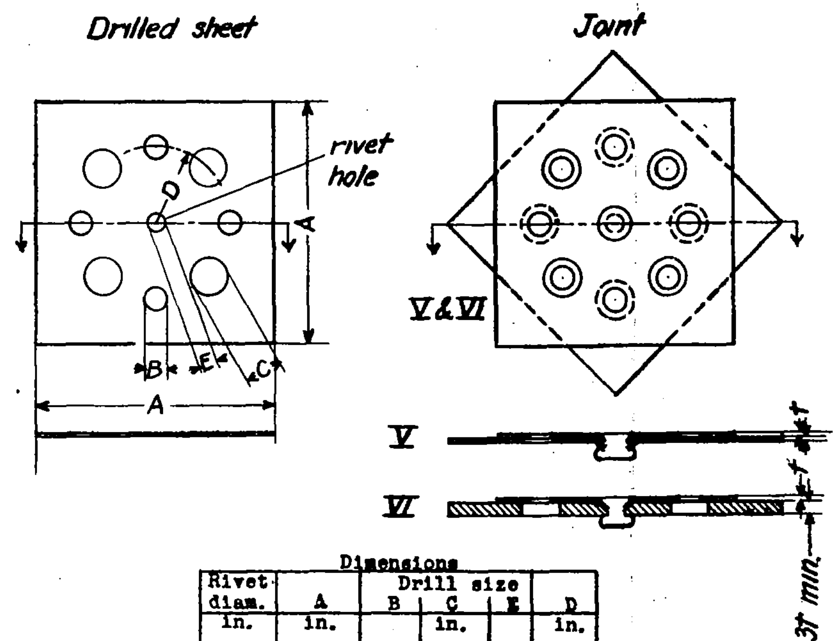
**Manufacturer 1 did not submit types III, IV, V, and VI.

-The points were too scattered to determine the sequence .

#Manufacturer 4 submitted tensile specimens but their range of d/t does not permit a good comparison with other specimens.



w, to nearest 1/16 in. = d(1 + 3 d/t), w_{max} = 12d, w_{min} = 6d

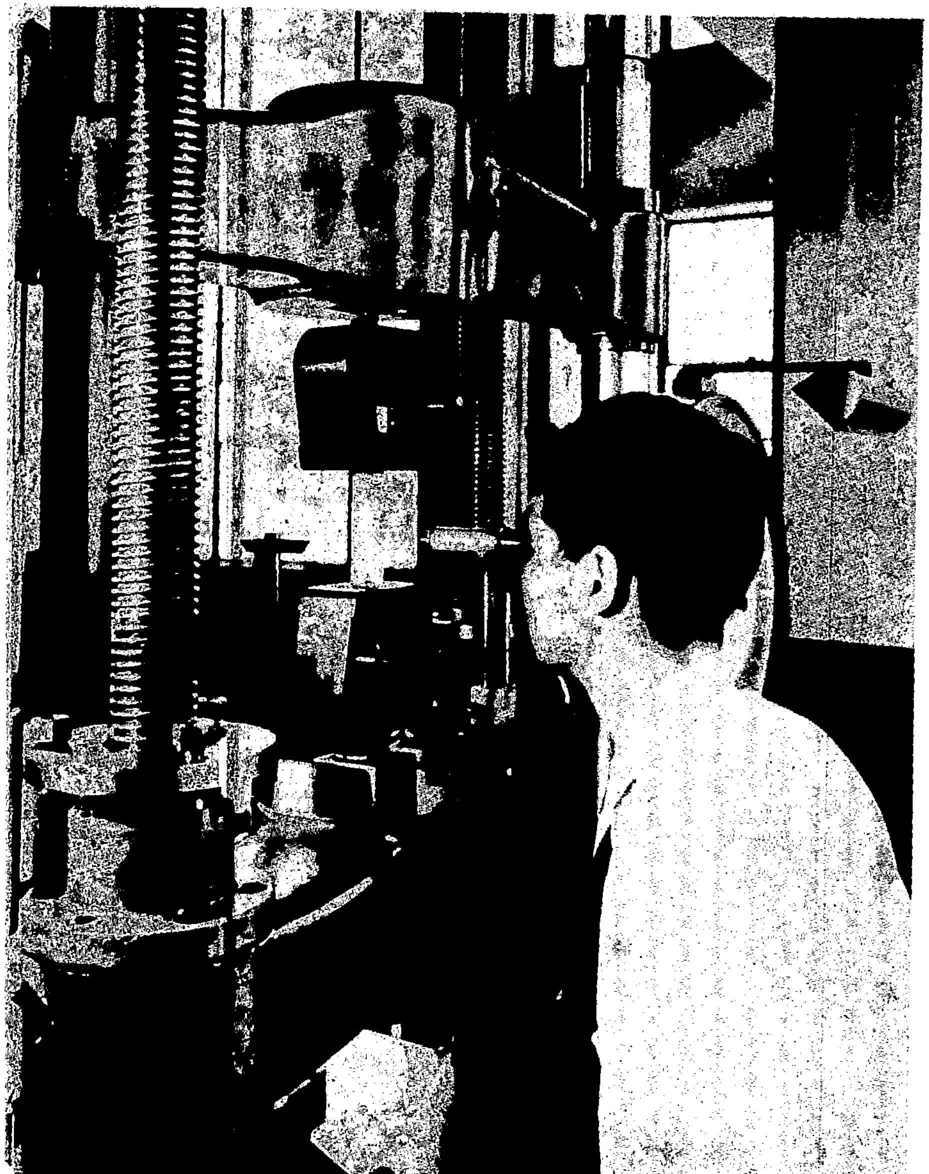


Dimensions

Rivet diam.	A	Drill size B	C	E	D
in.	in.		in.		in.
3/32	1 1/4	#33	3/16	As required	3/8
1/8	1 5/8	#19	1/4		1/2
5/32	2	#11	5/16		5/8
3/16	2 1/2	"F"	3/8		3/4
1/4	3 1/4	"O"	1/2		1

Figure 1

Shearing specimens I, II, III, and IV, left; tensile specimens V and VI, above.



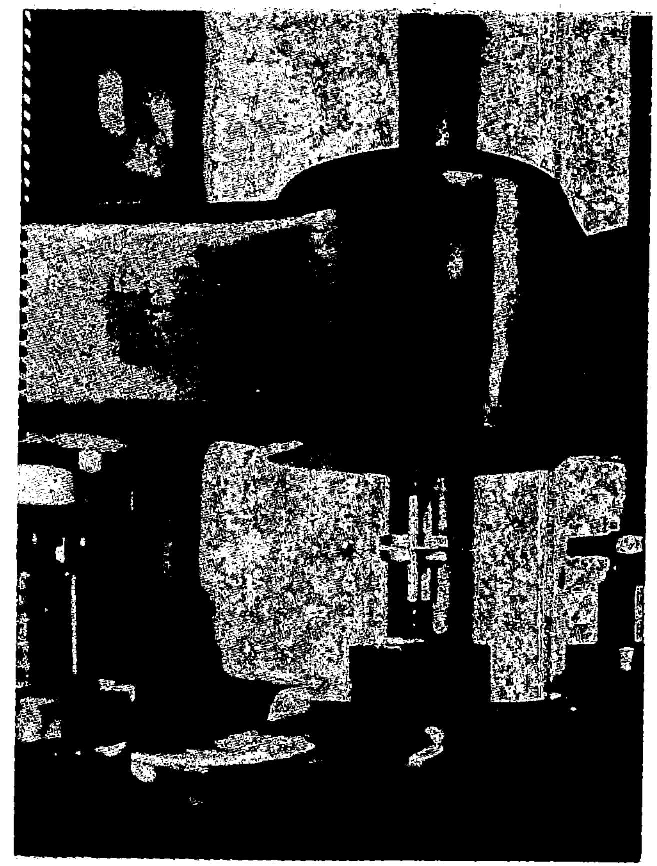


Figure 2

Left, measuring the slippage of a shearing specimen by means of a Brinell microscope.

Above, tensile specimen and fixture.

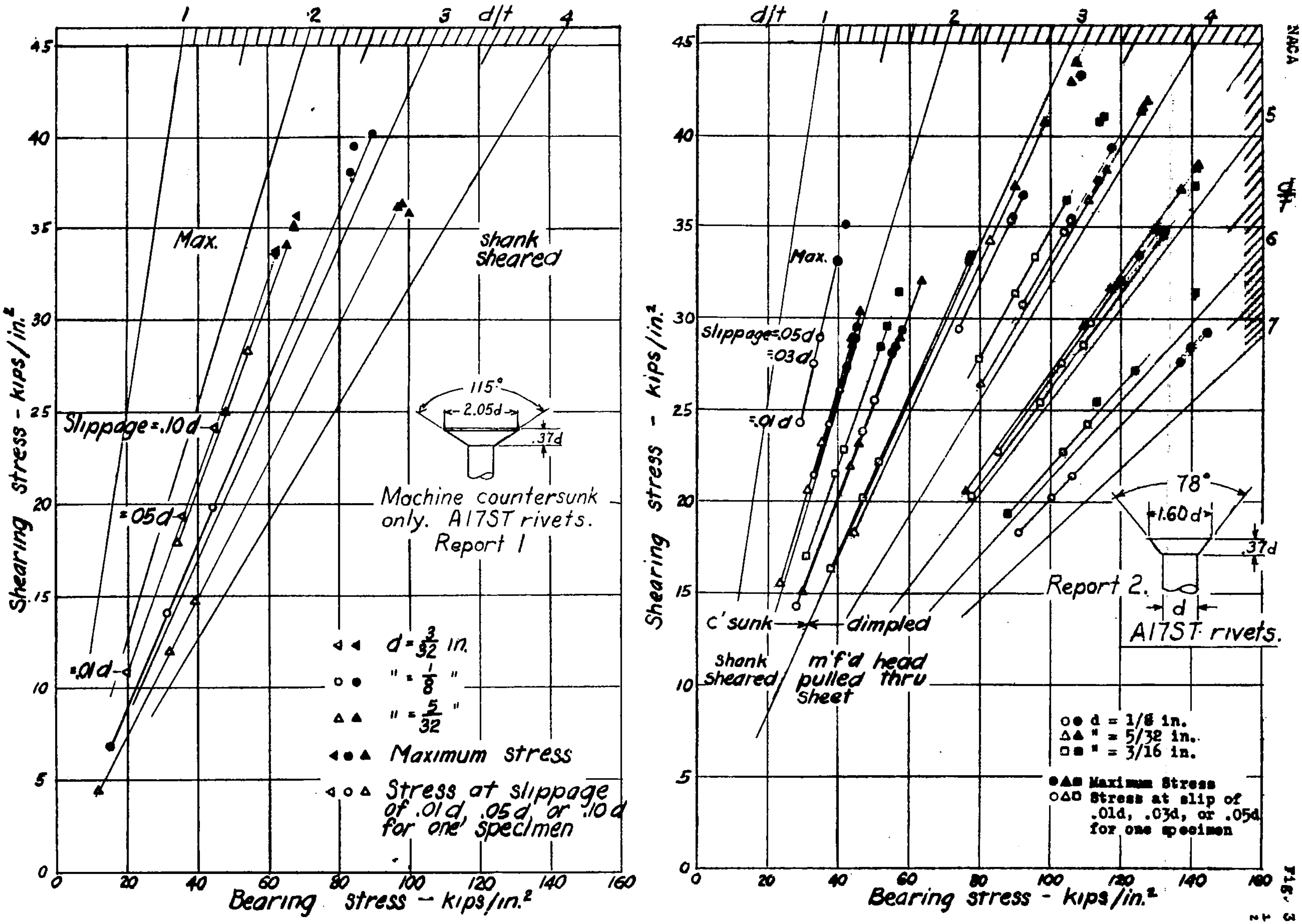


Figure 3.- Shearing results for type I specimens.

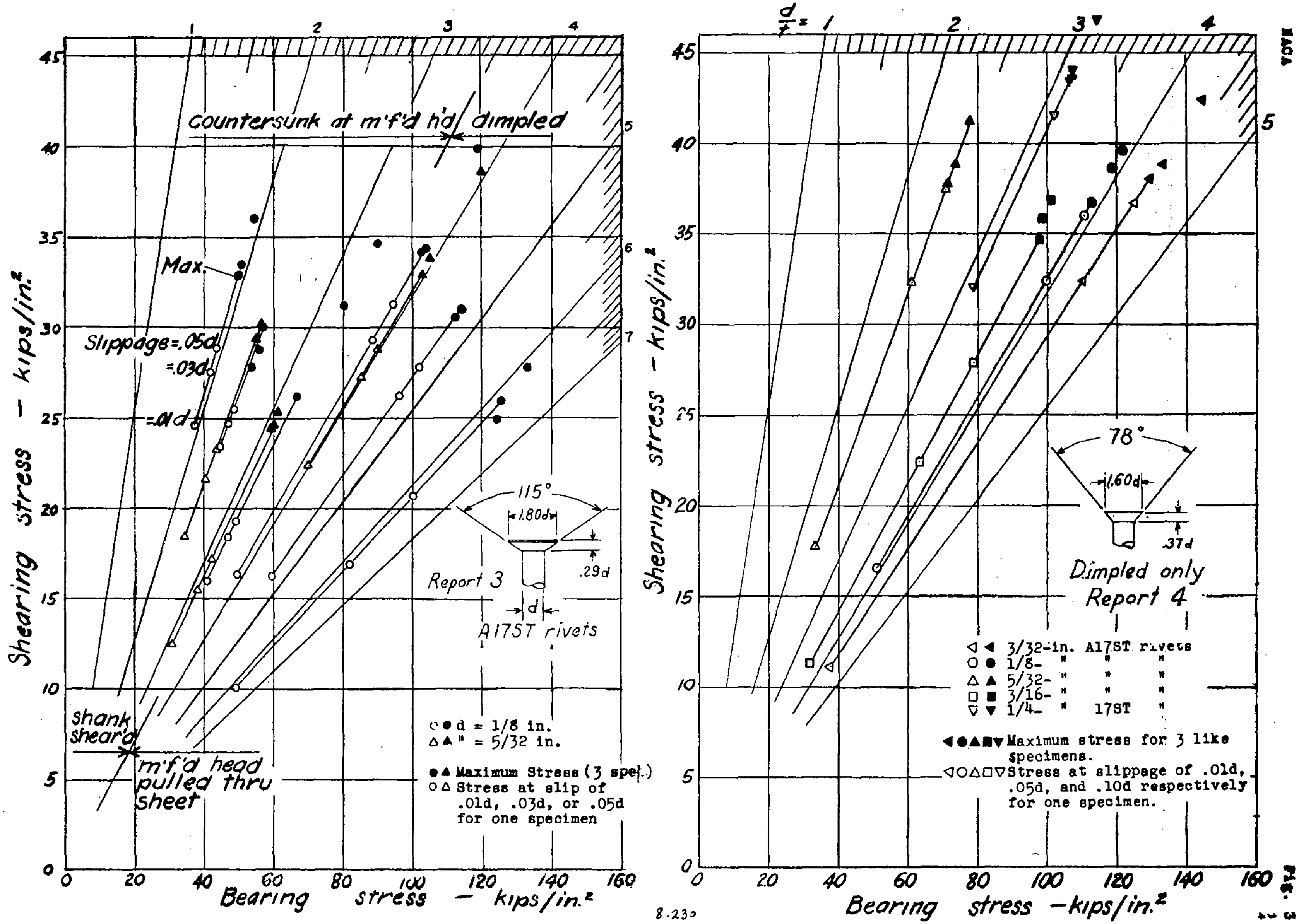


Figure 3.- Continued.

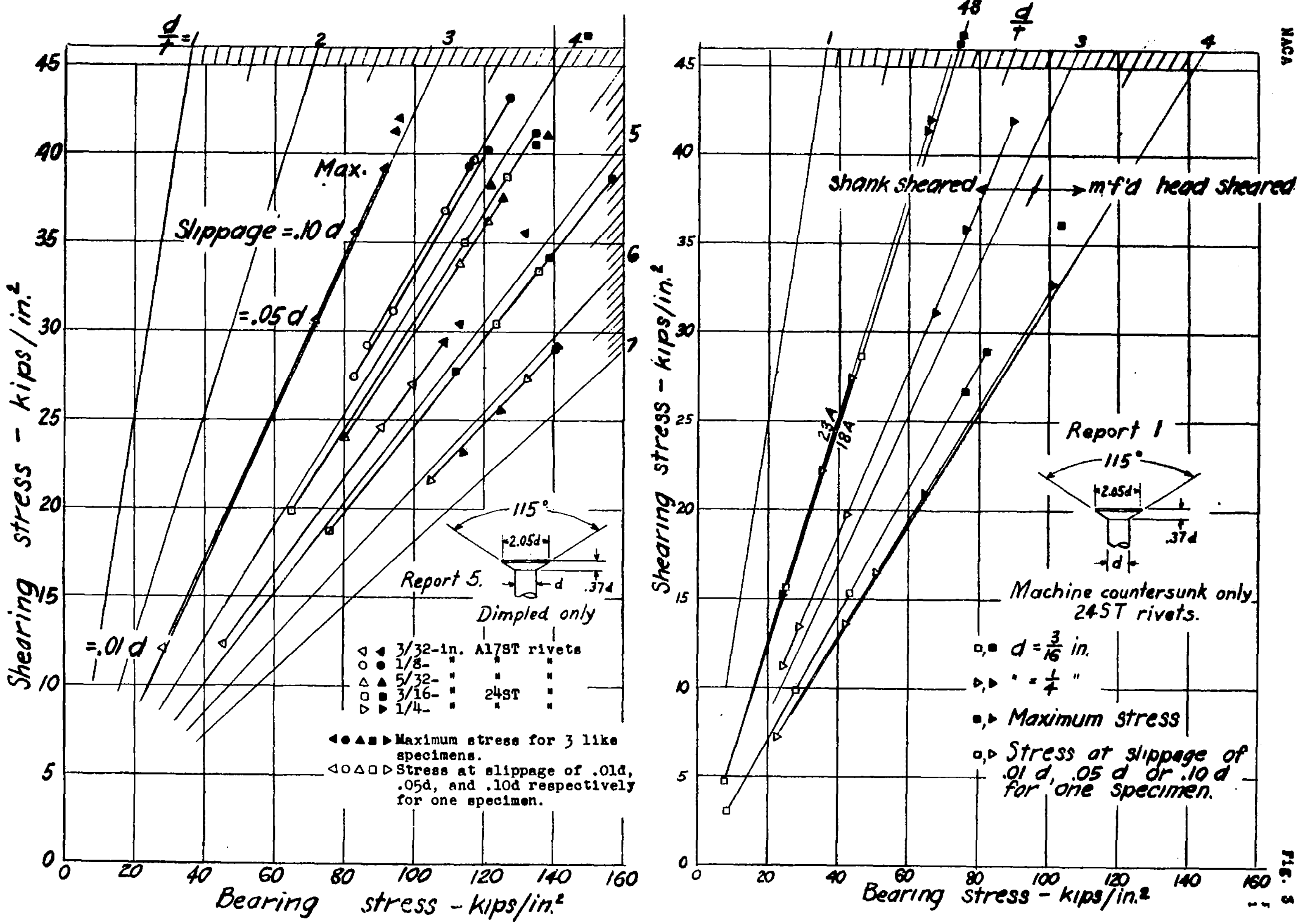


Figure 3.- Continued.

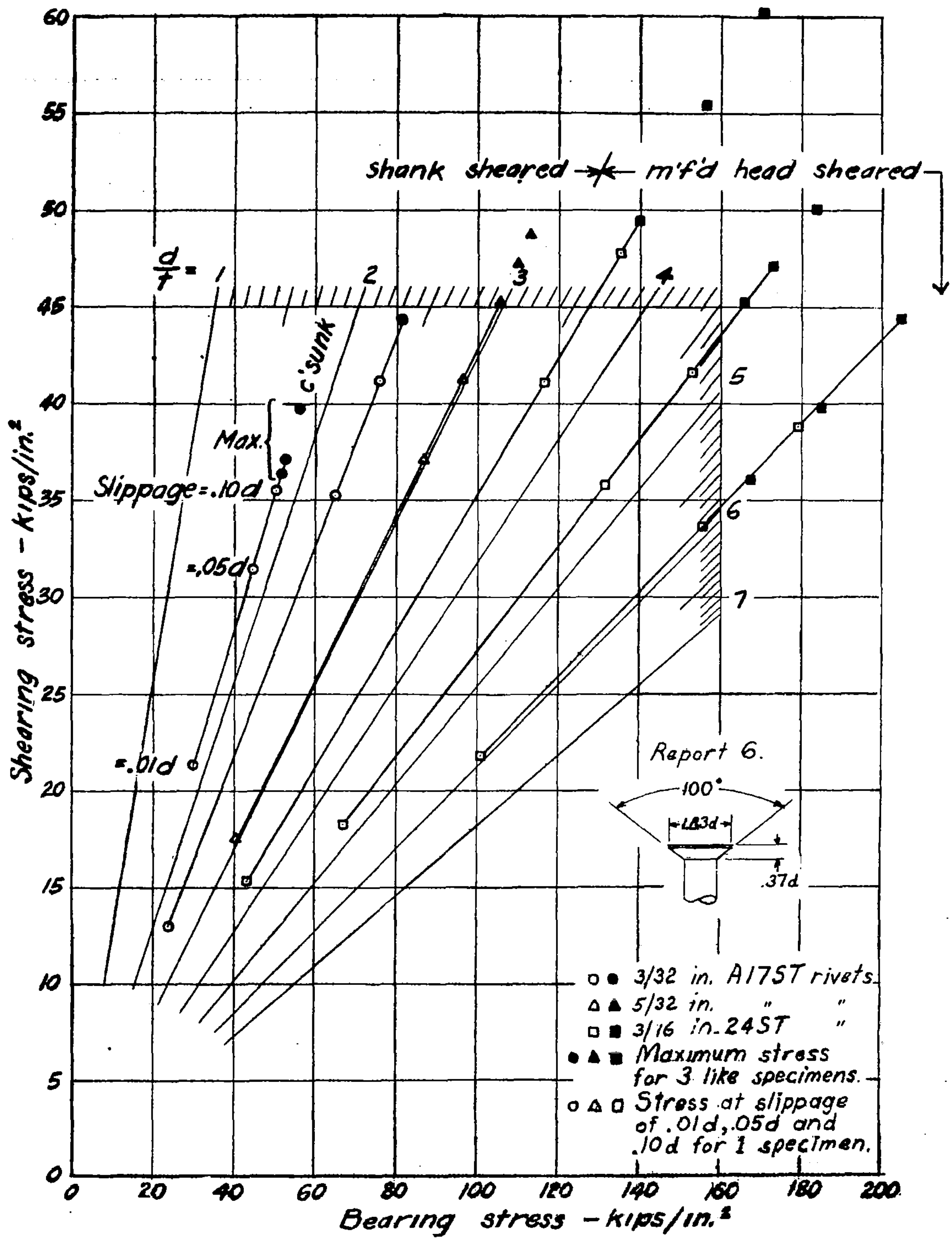


Figure 3.- Concluded.

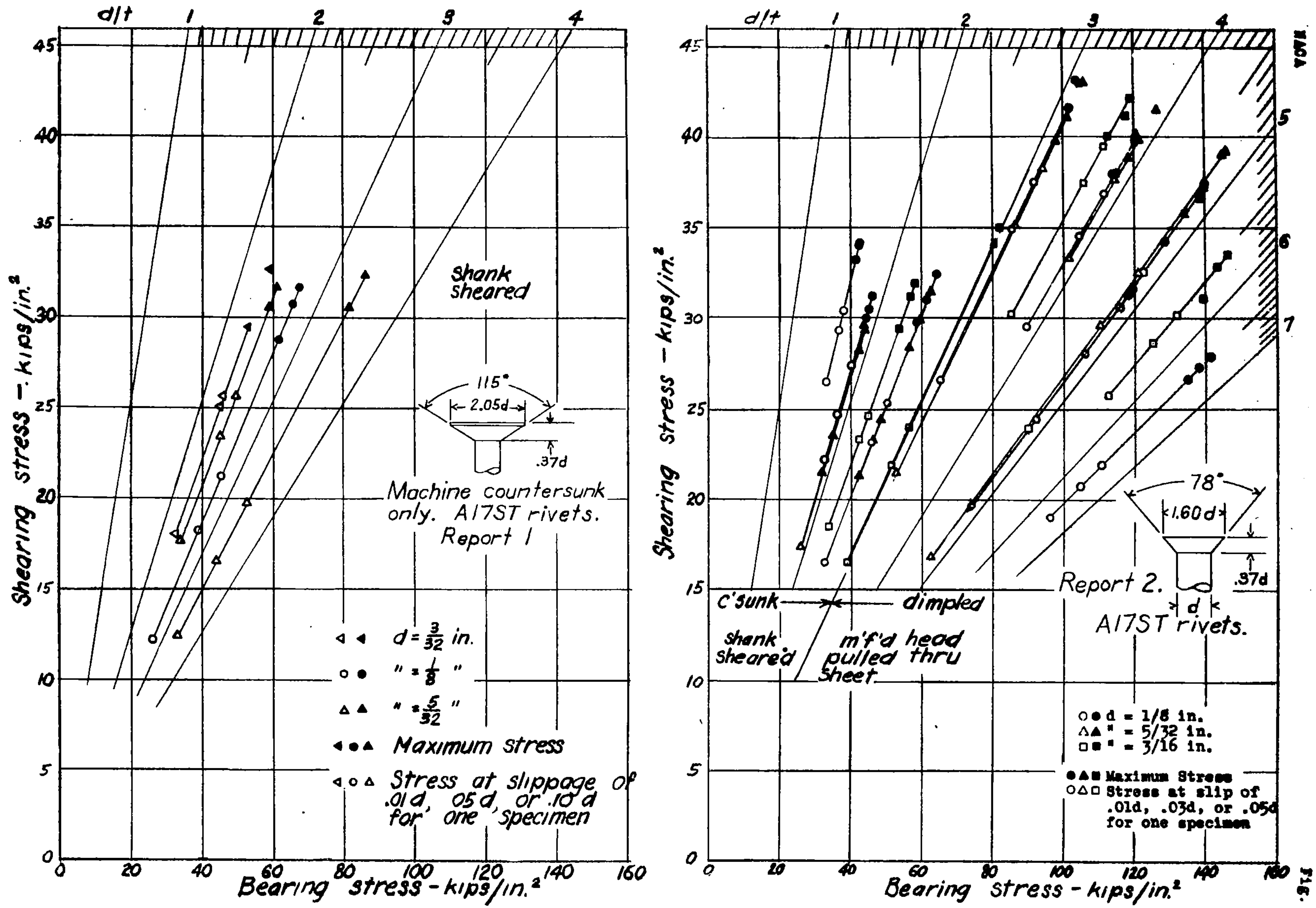


Figure 4. - Shearing results for type II specimens.

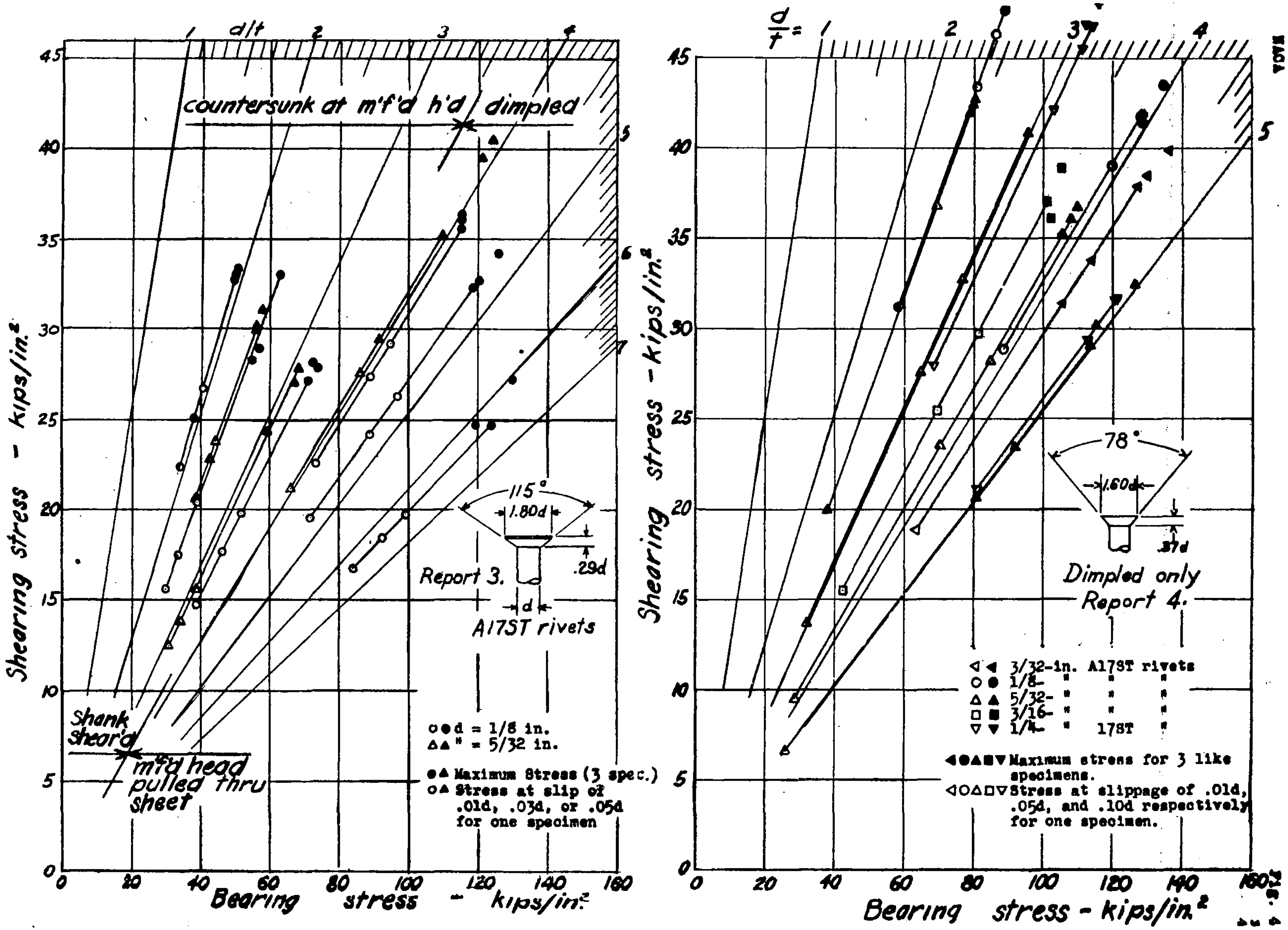


Figure 4.- Continued.

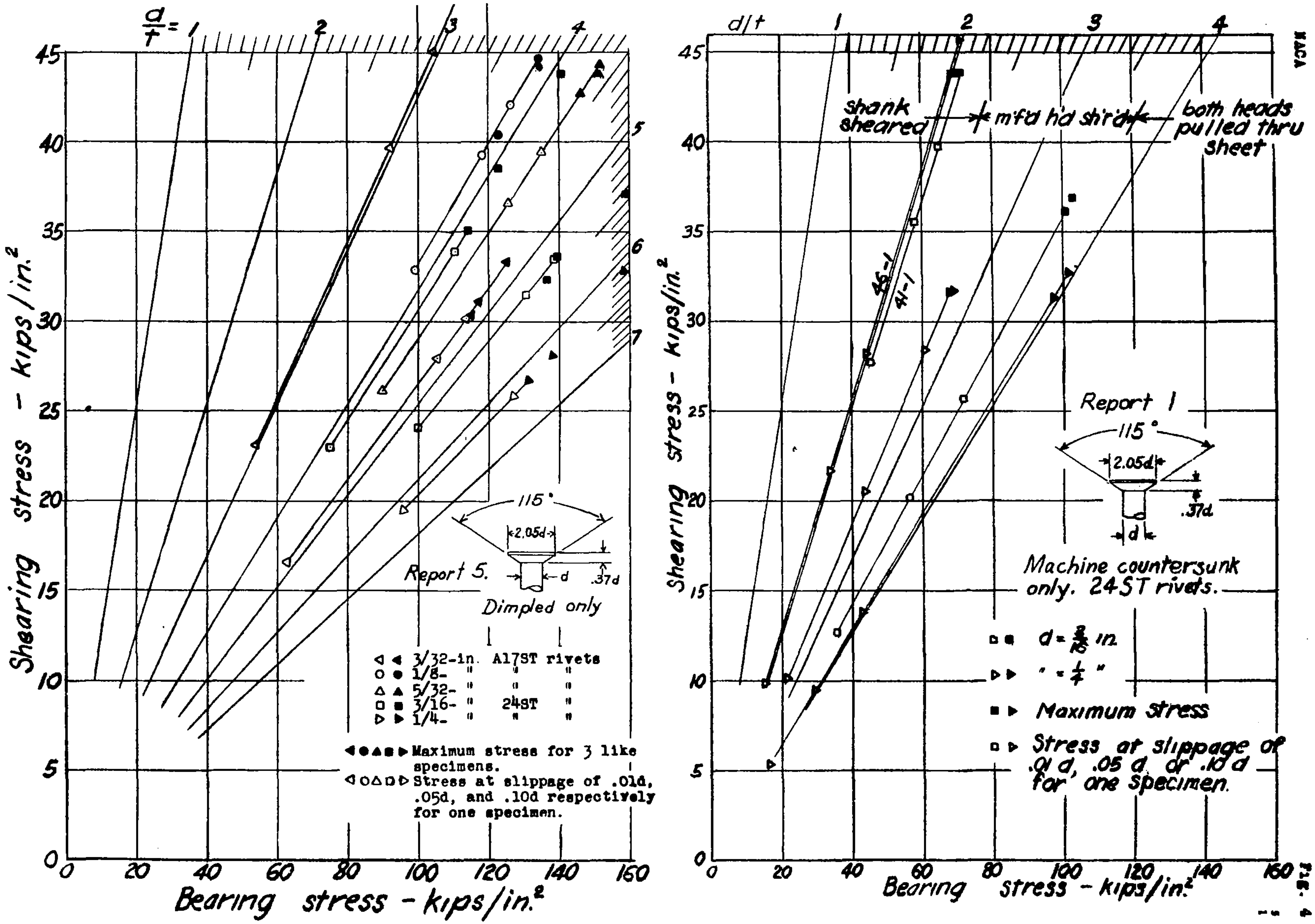


Figure 4.- Continued.

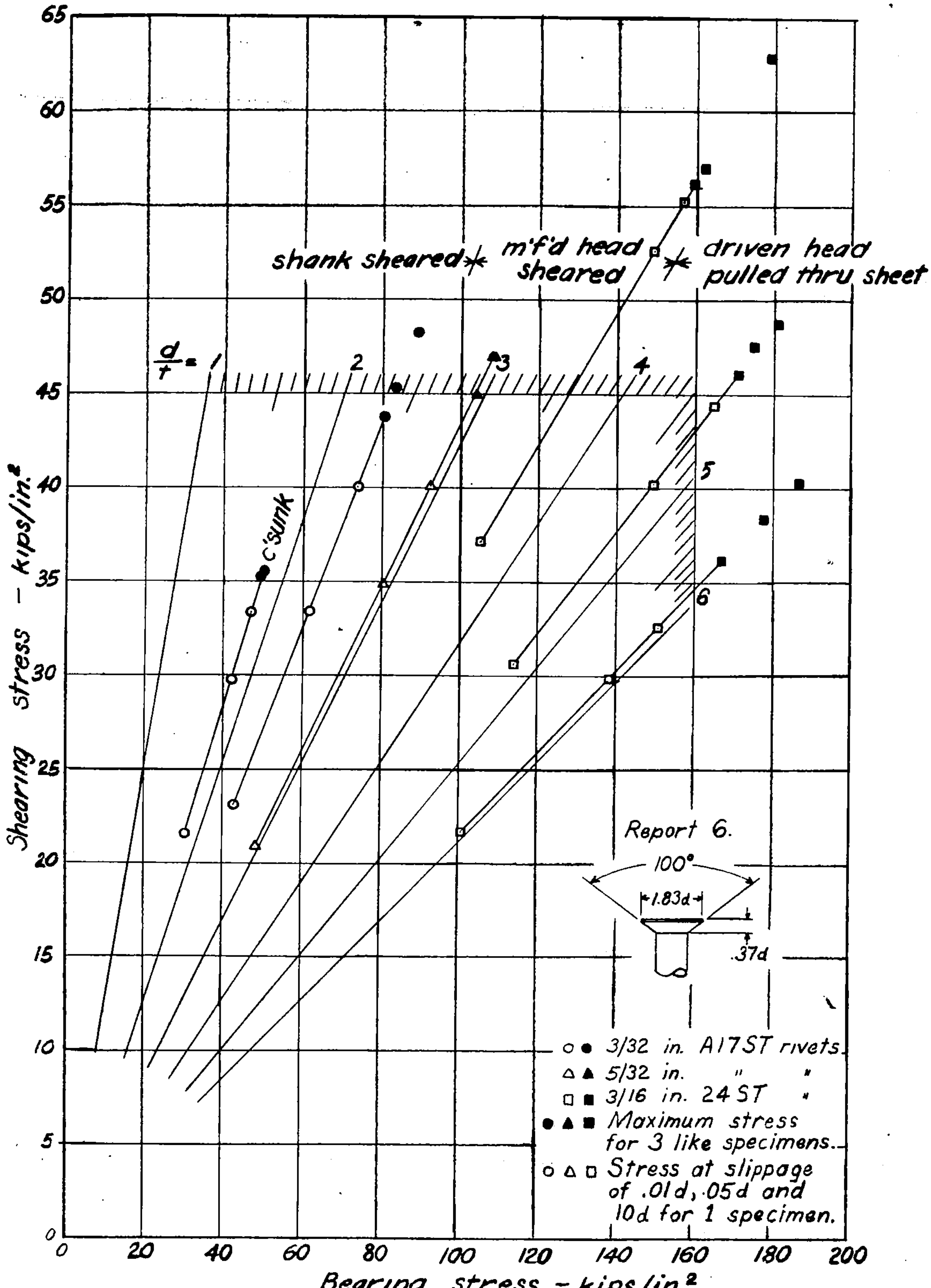


Figure 4.- Concluded.

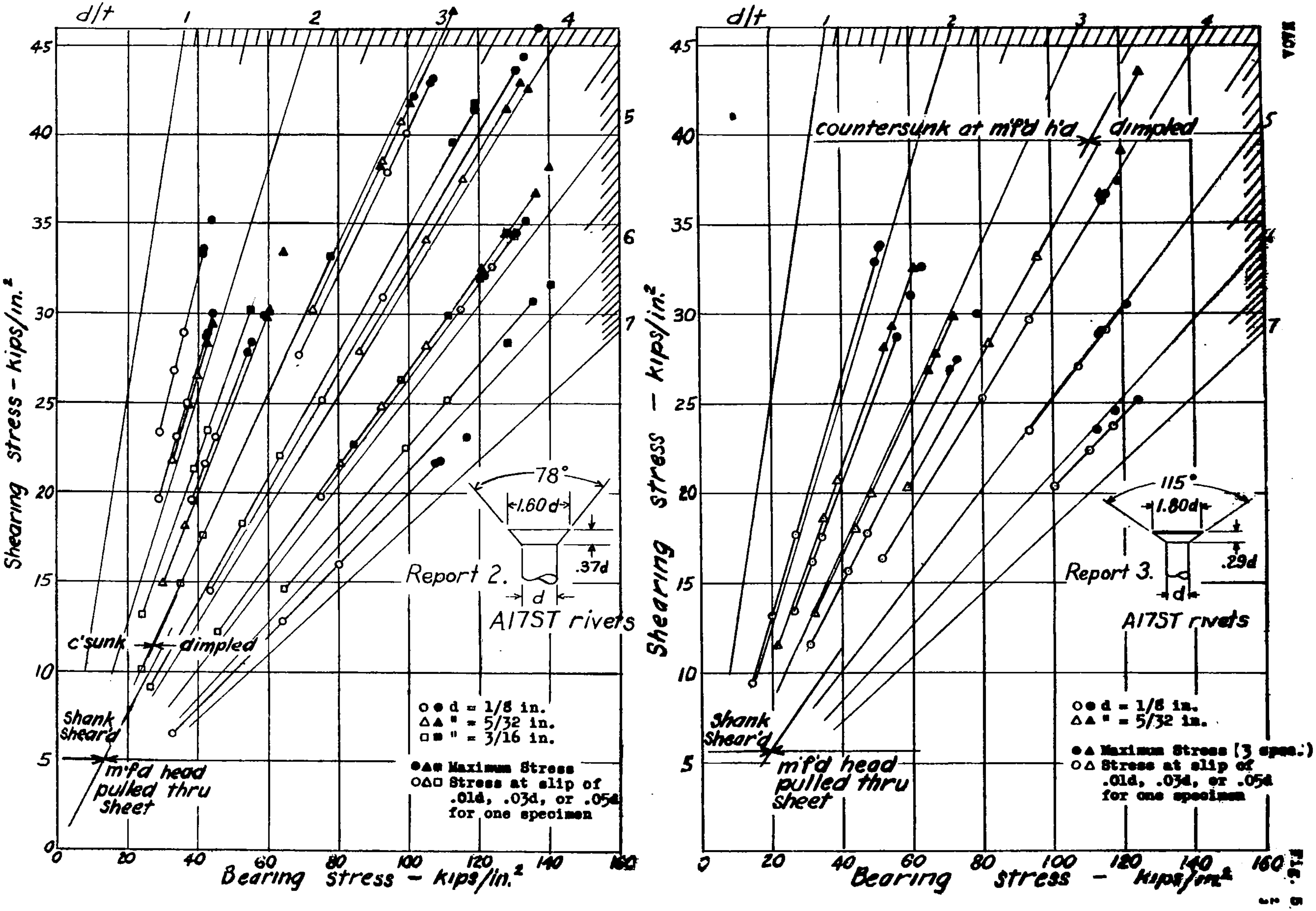


Figure 5.- Shearing results for type III specimens.

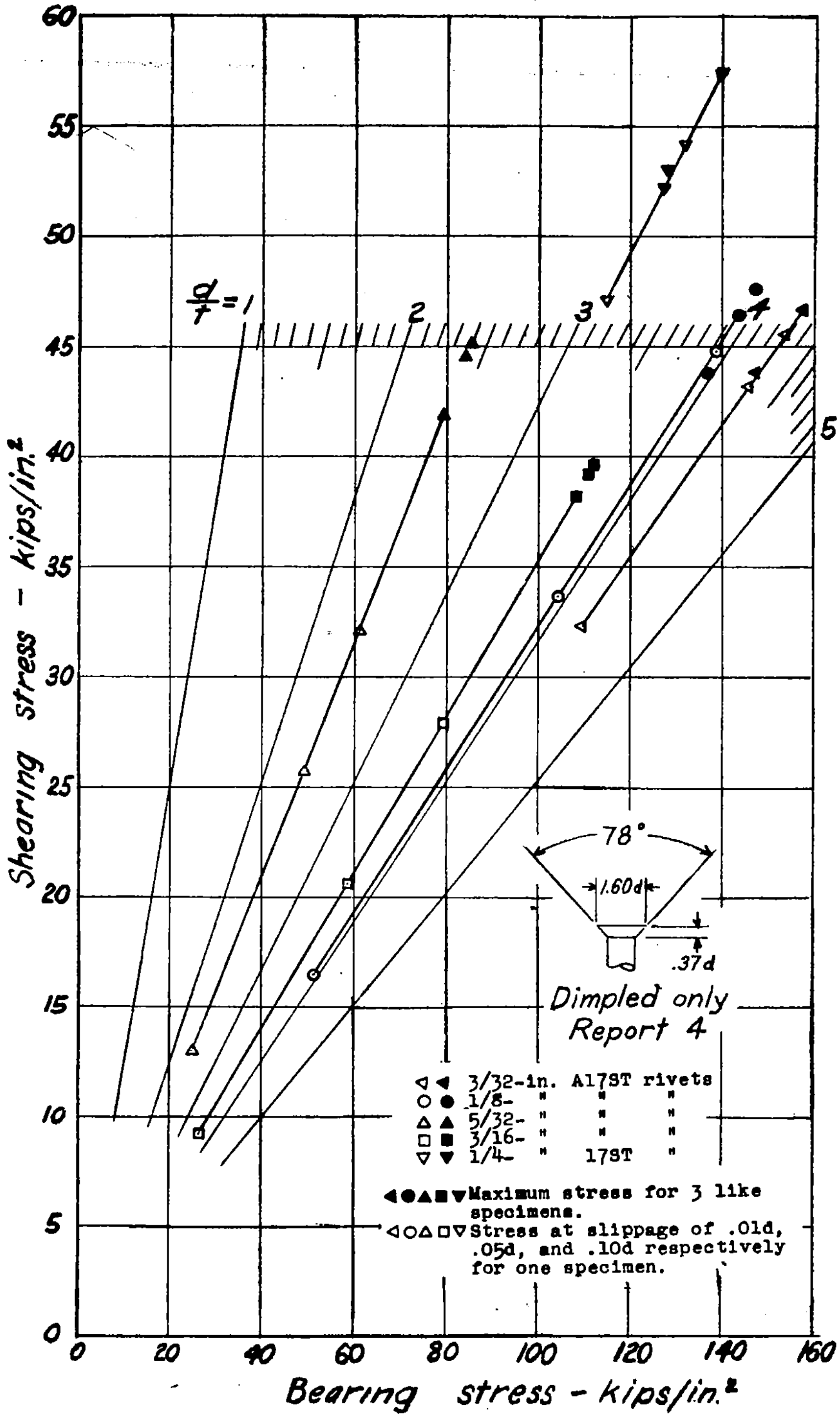


Figure 5.- Continued.

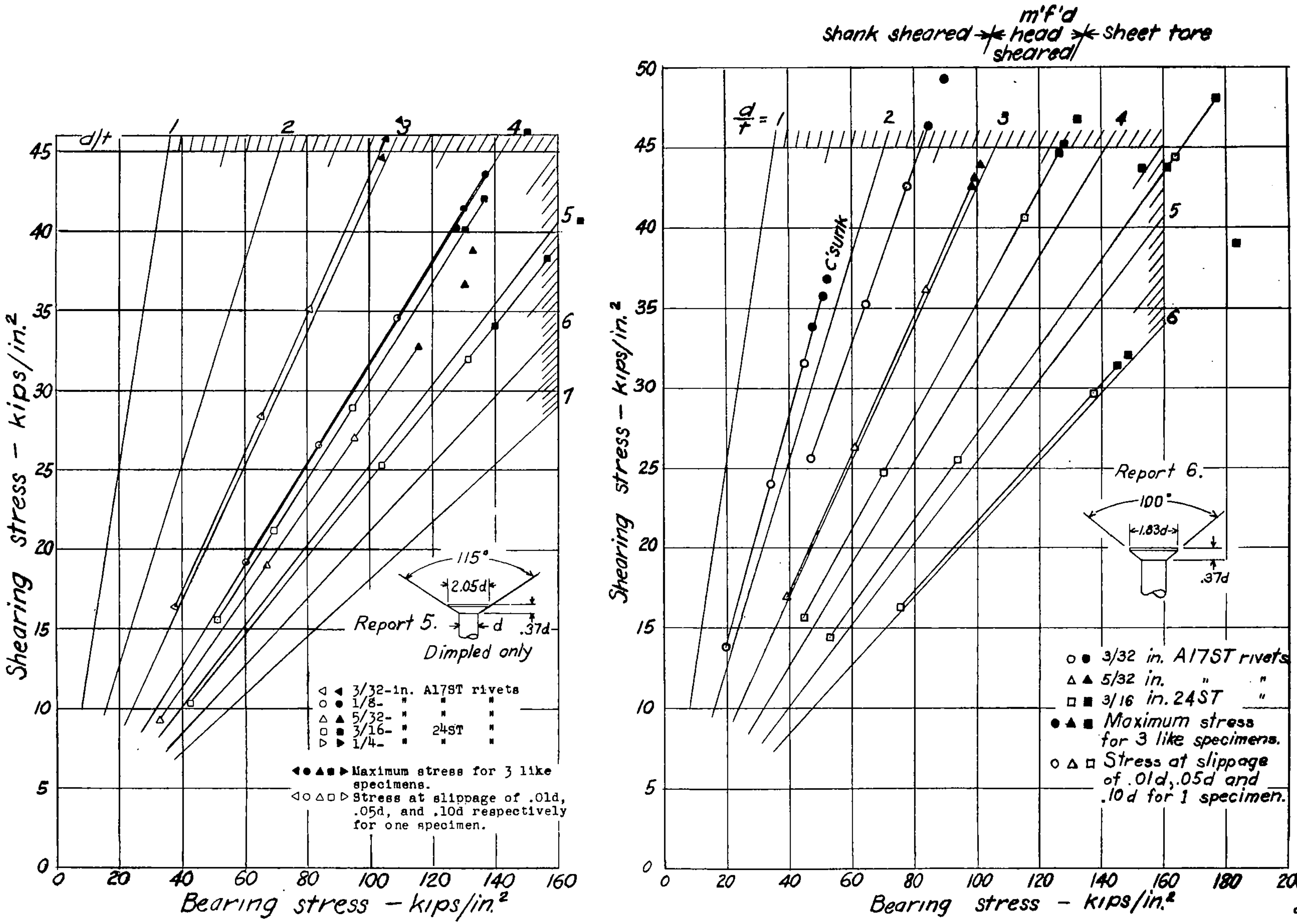


Figure 5.- Concluded.

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Fig. 5

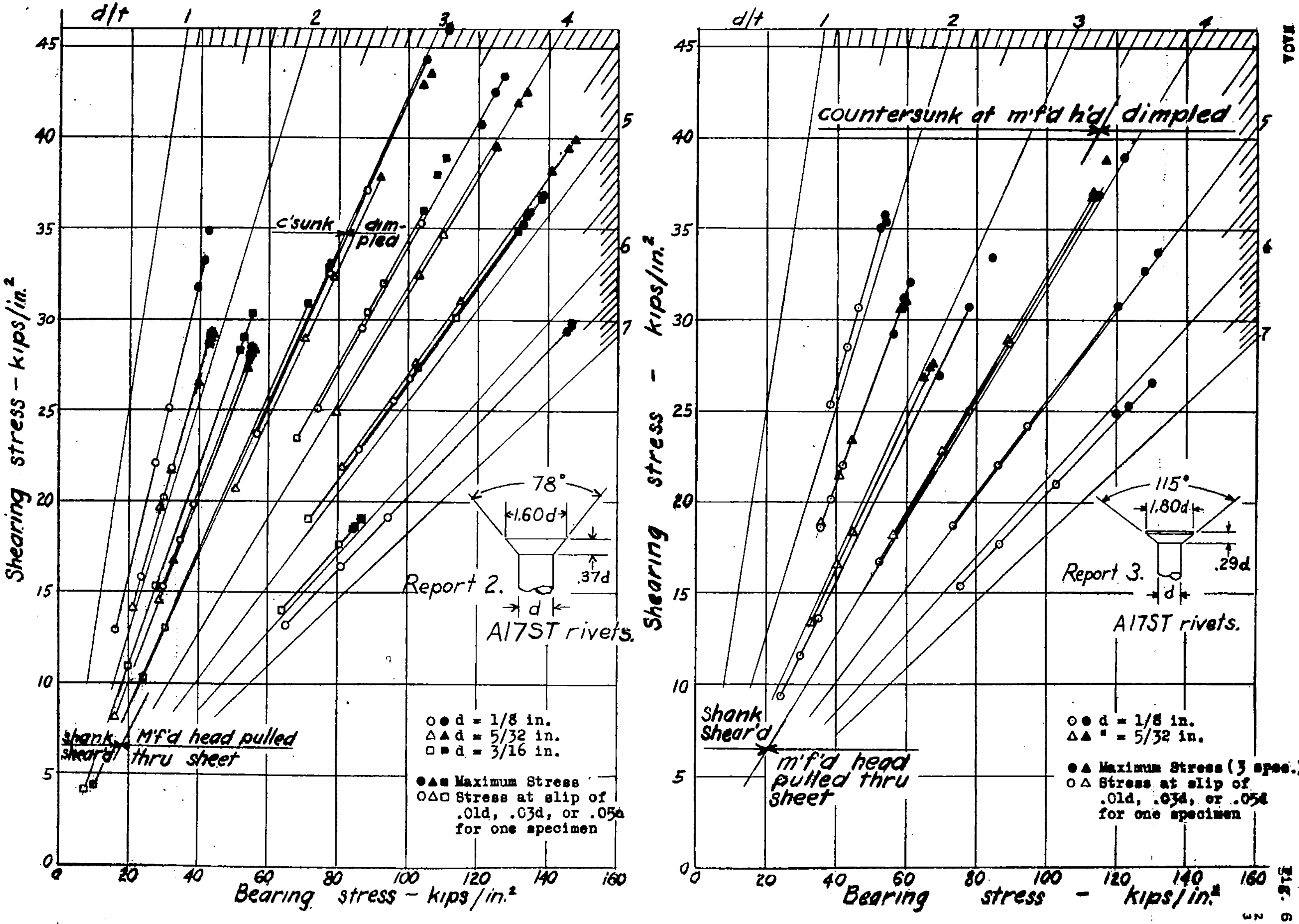
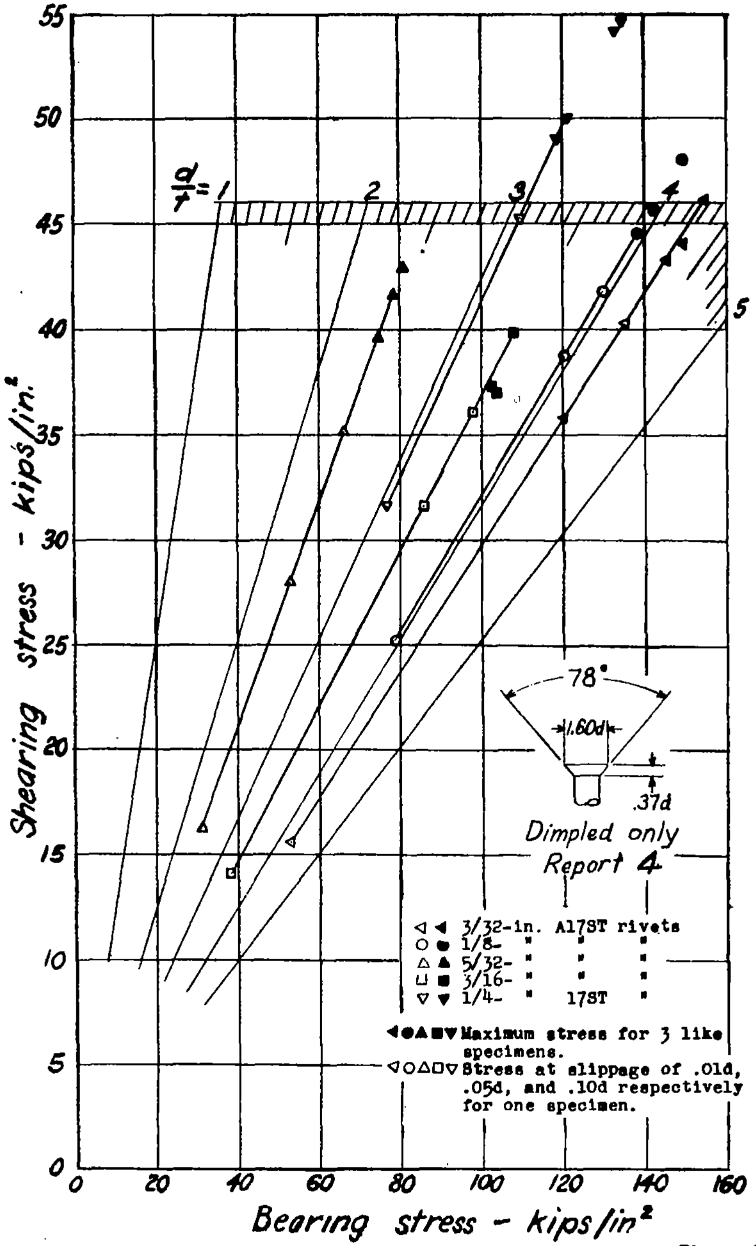


Figure 6.- Shearing results for type IV specimens.



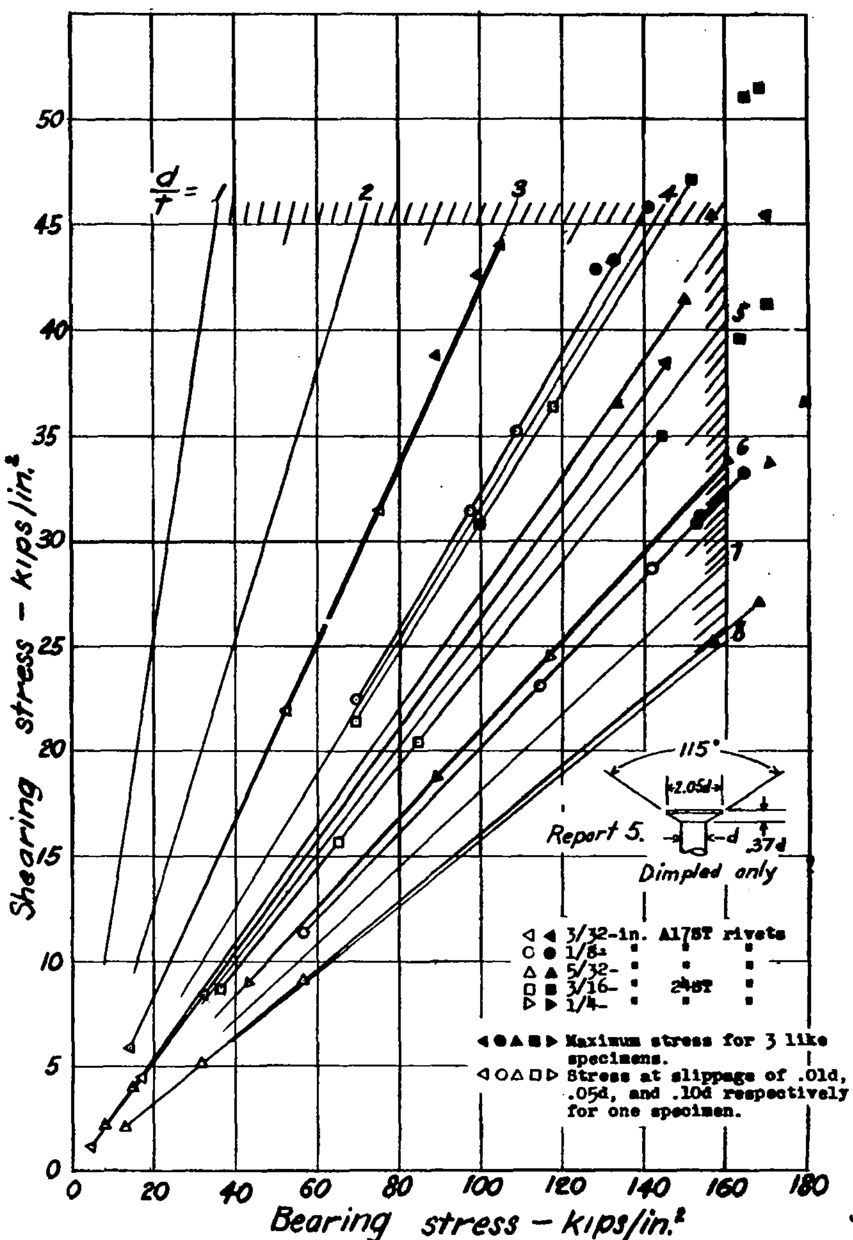


Figure 6.- Continued.

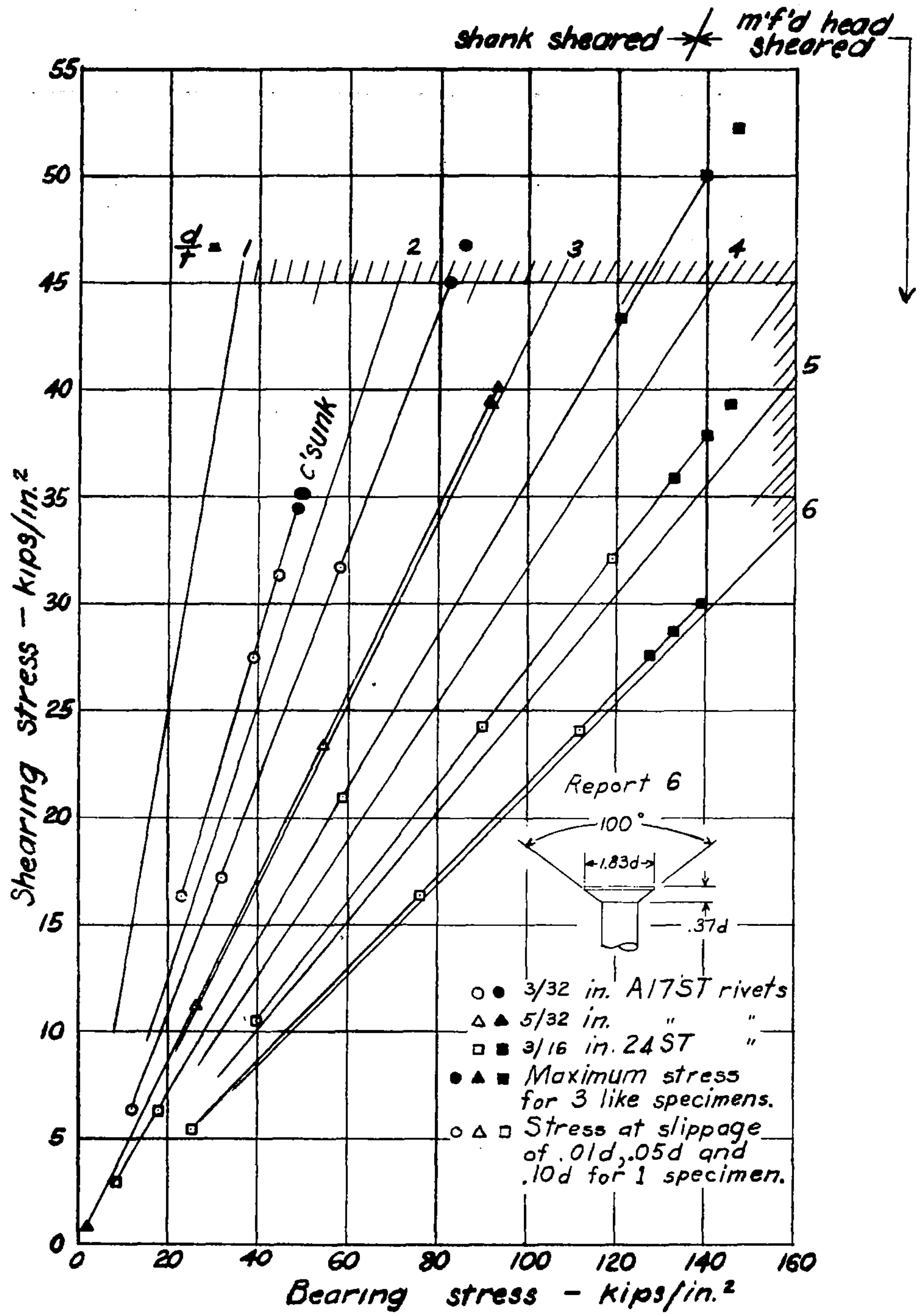


Figure 6.- Concluded.

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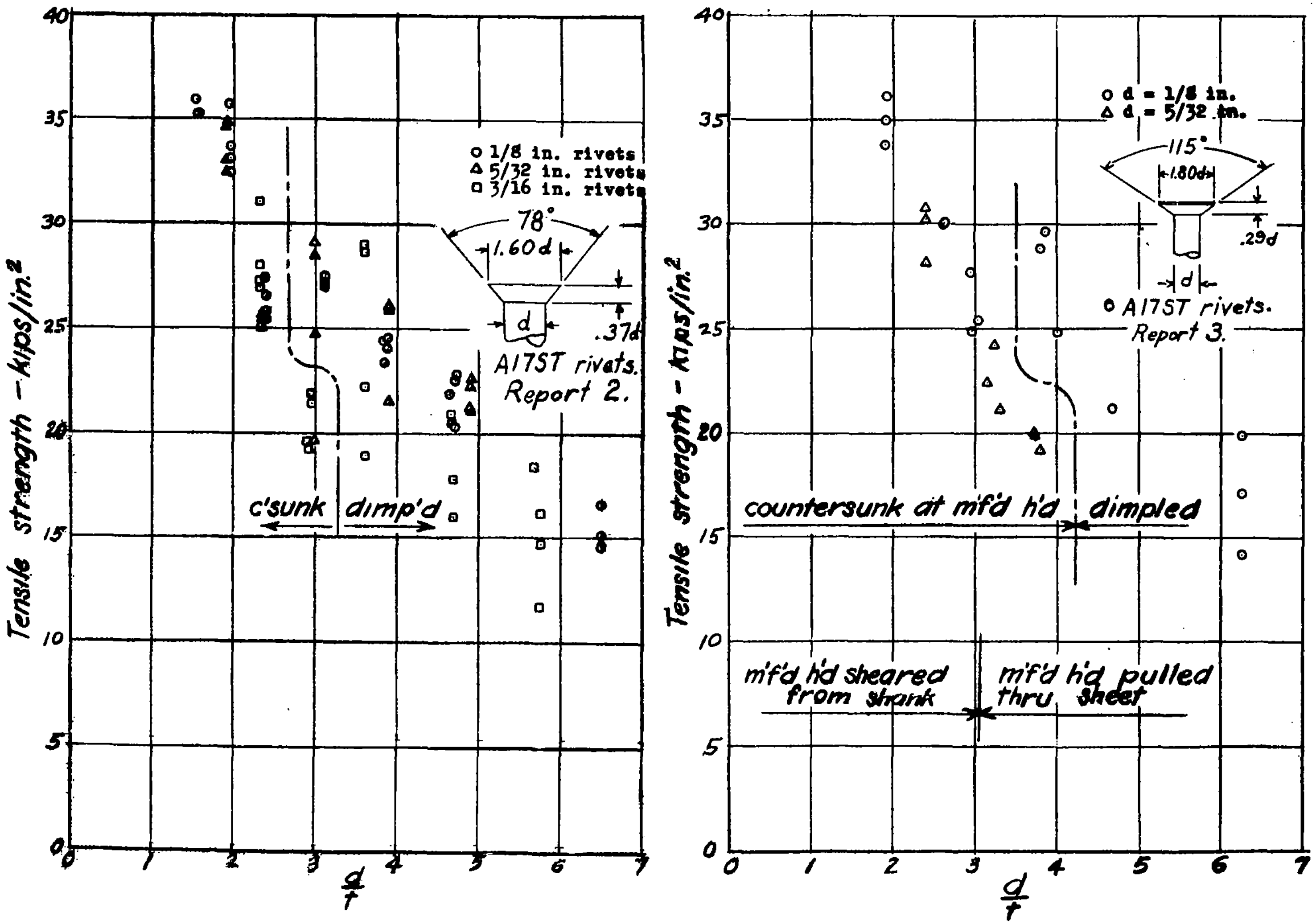
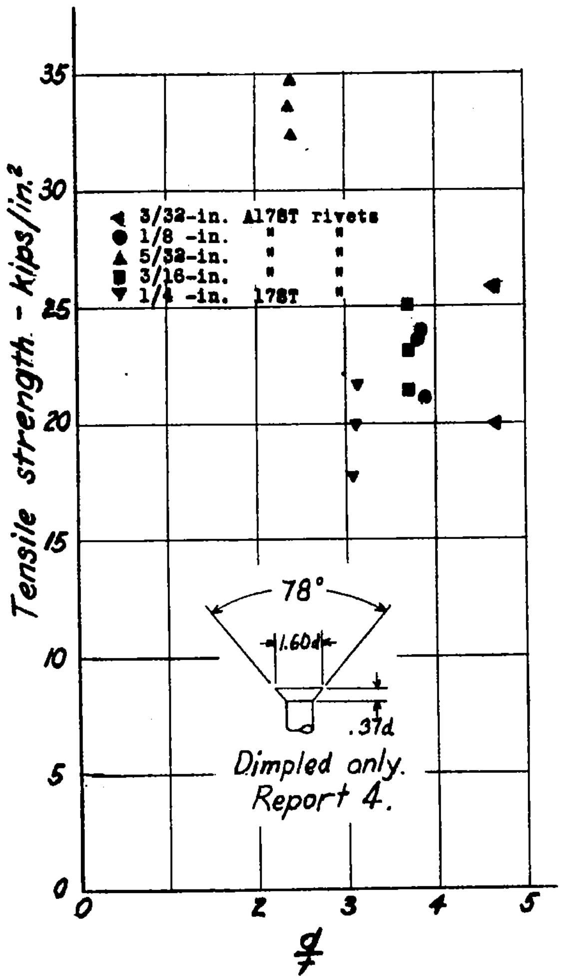
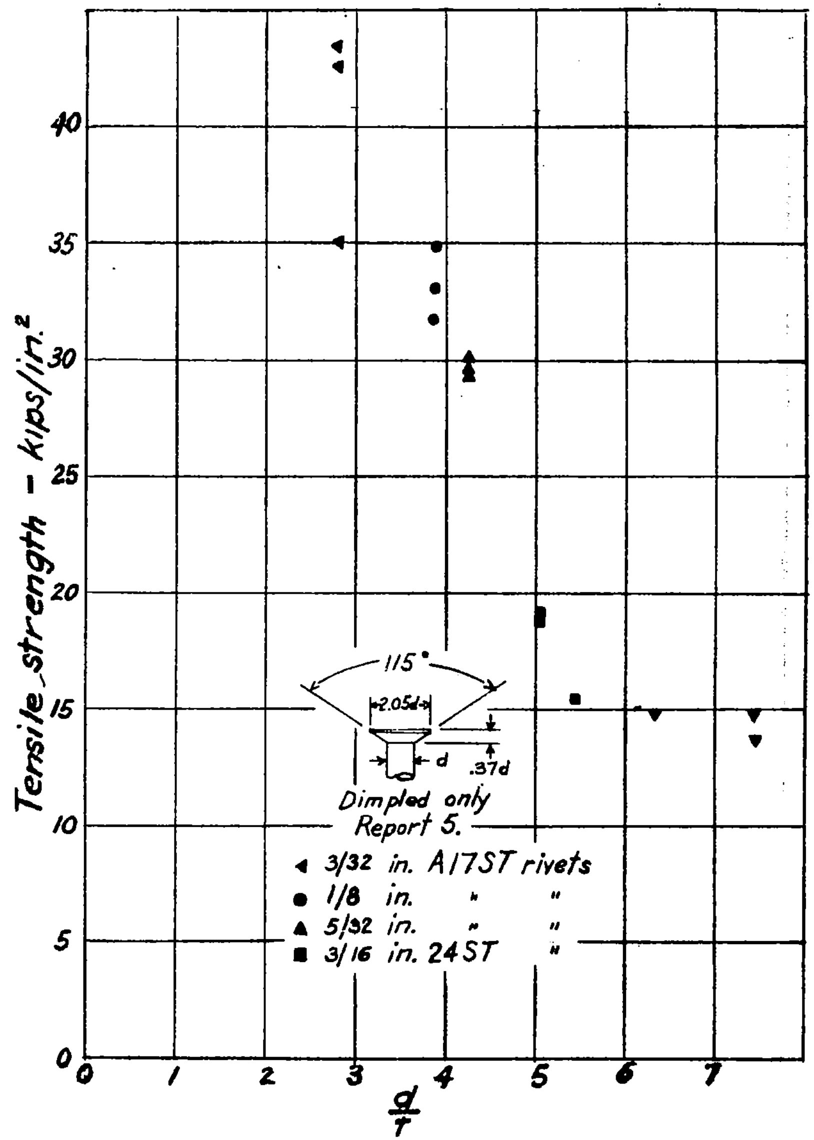


Figure 7.- Tensile results for type V specimens.

Fig. 7





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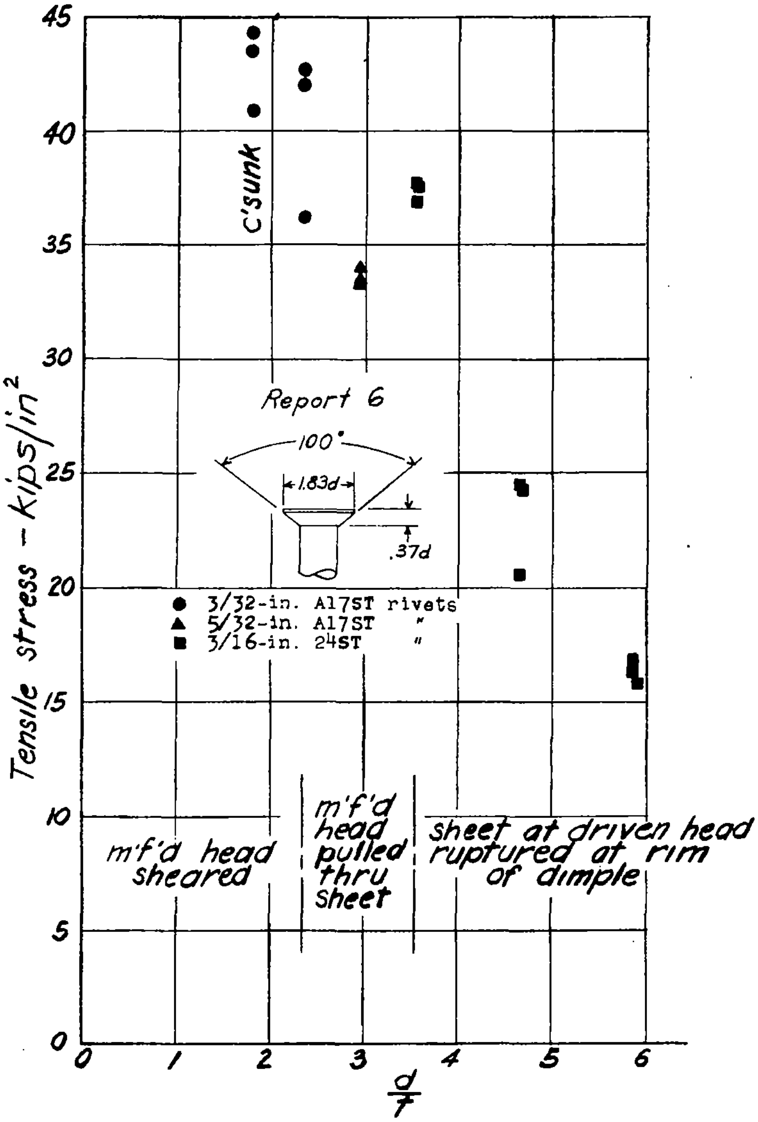

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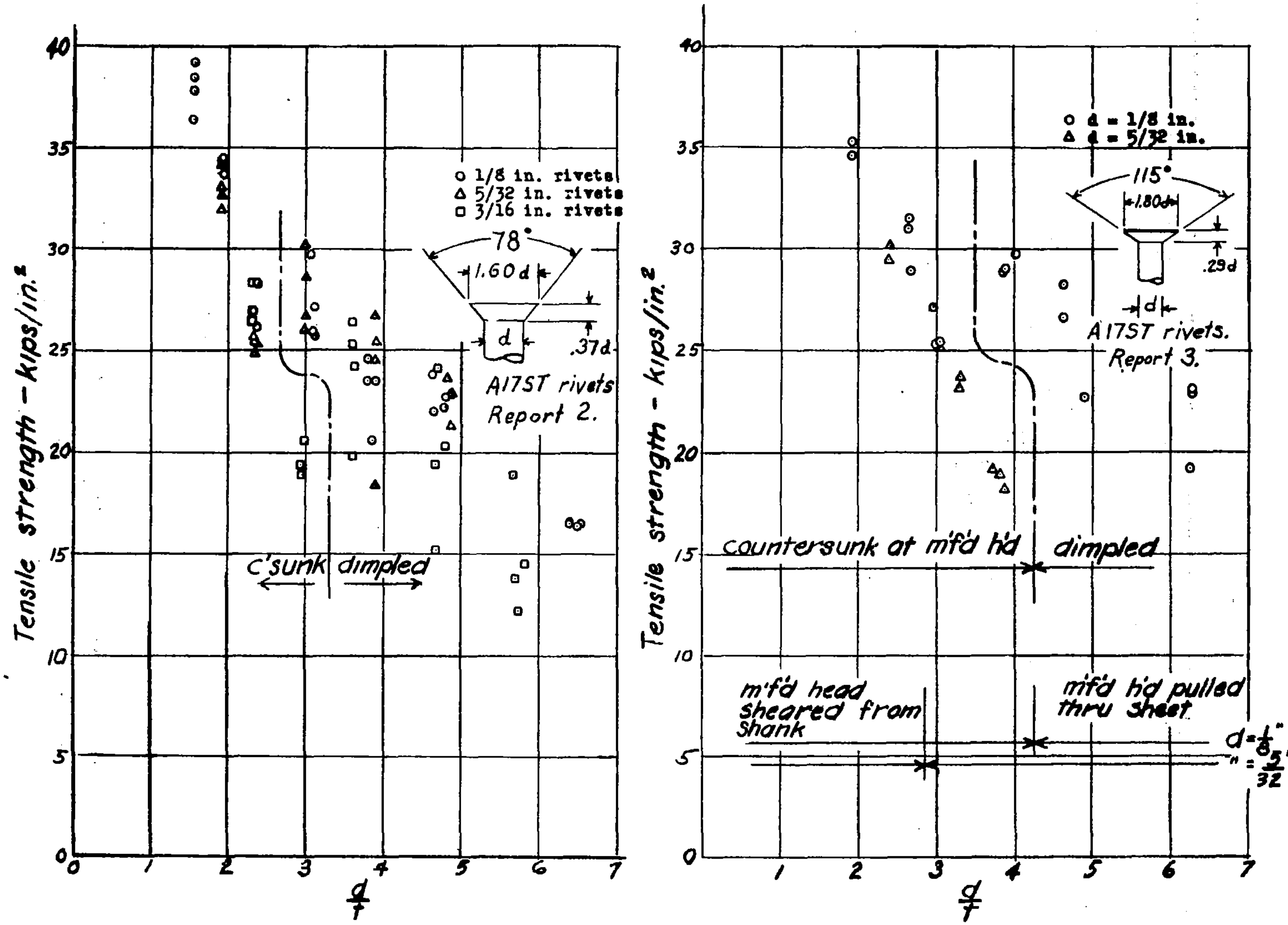
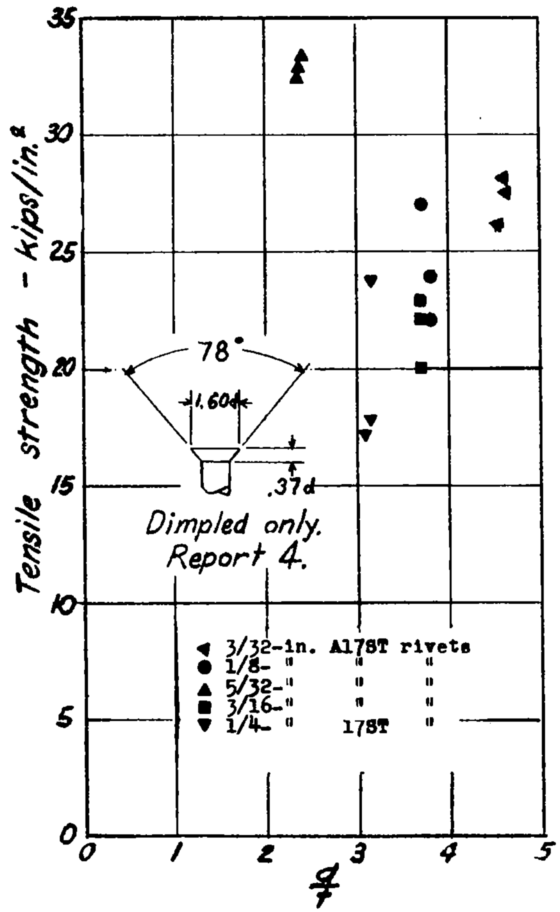
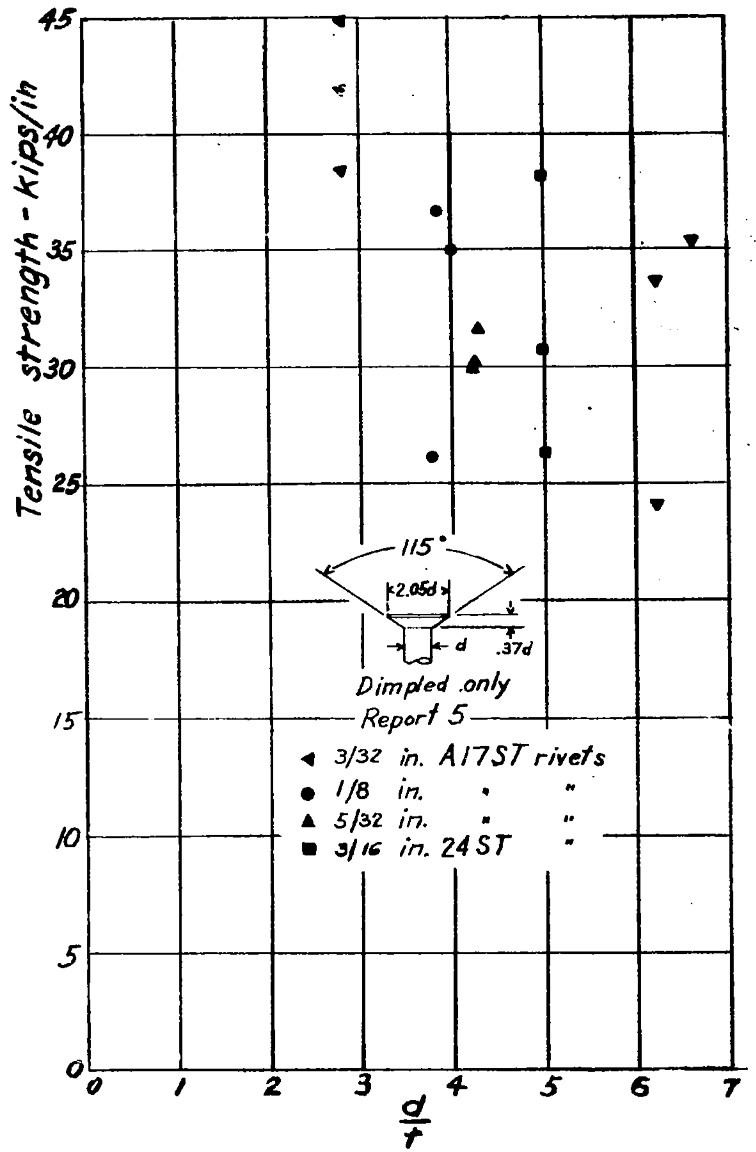


Figure 8.- Tensile results for type VI specimens.





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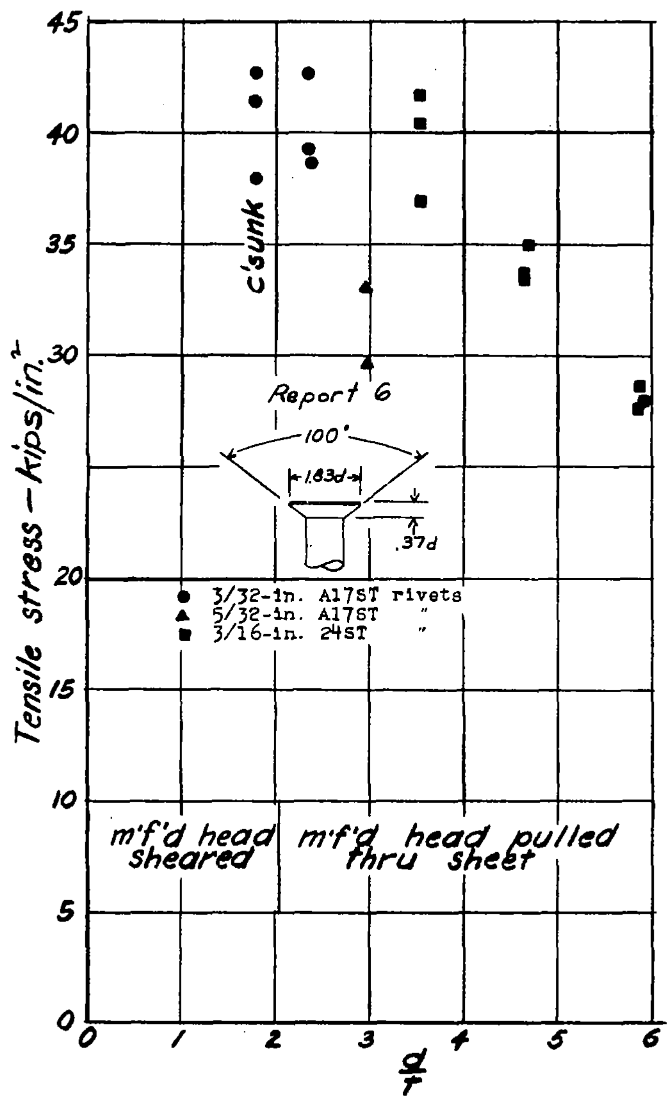

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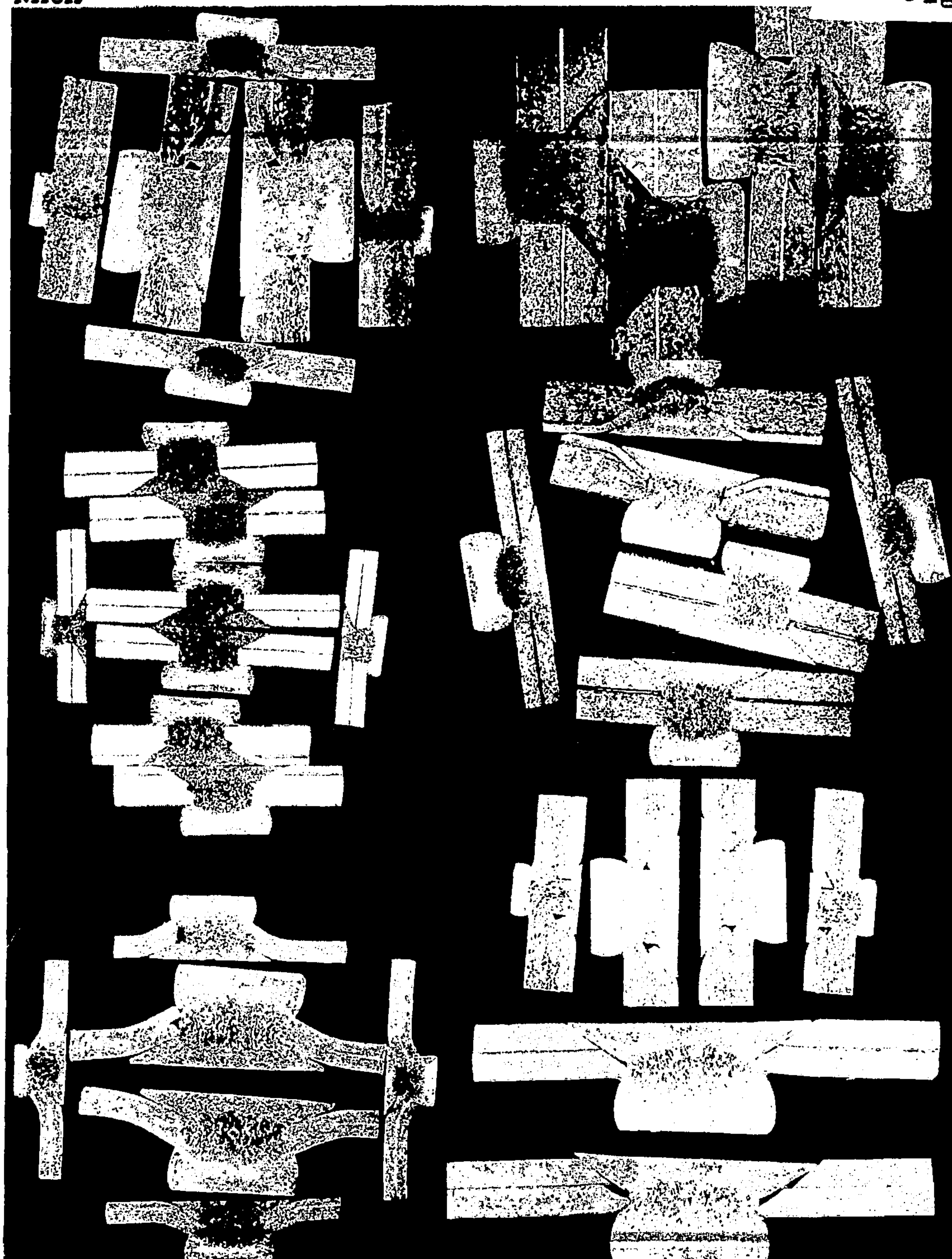


Figure 9. Cross section of specimens from reports 1 and 5.

The specimen at the lower right consists of a $\frac{1}{4}$-in. 24ST rivet in 0.064-in. sheets. A shearing load of 400 lb per rivet had been applied prior to sectioning, otherwise this specimen is nominally the same as the one directly above it.

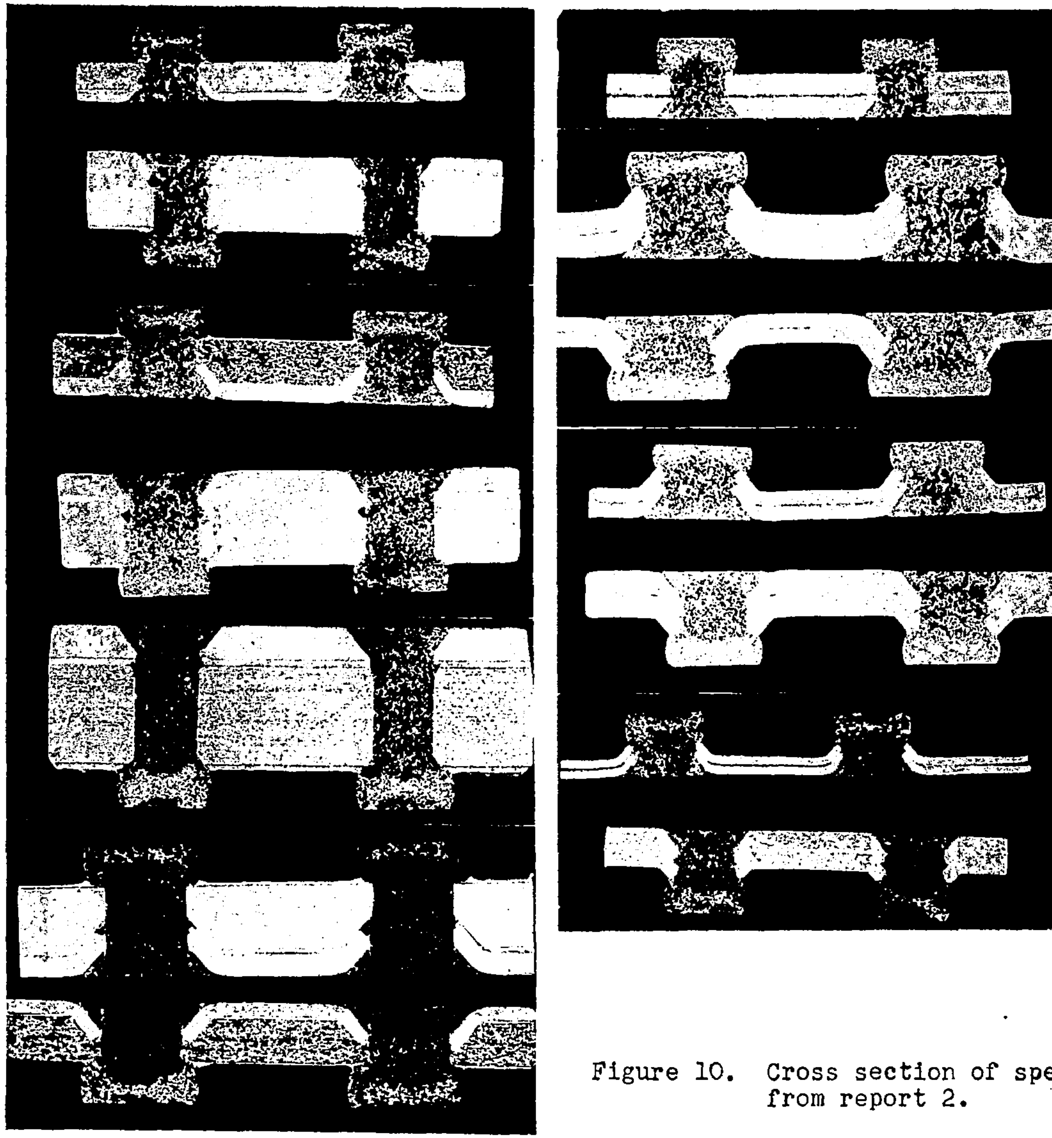
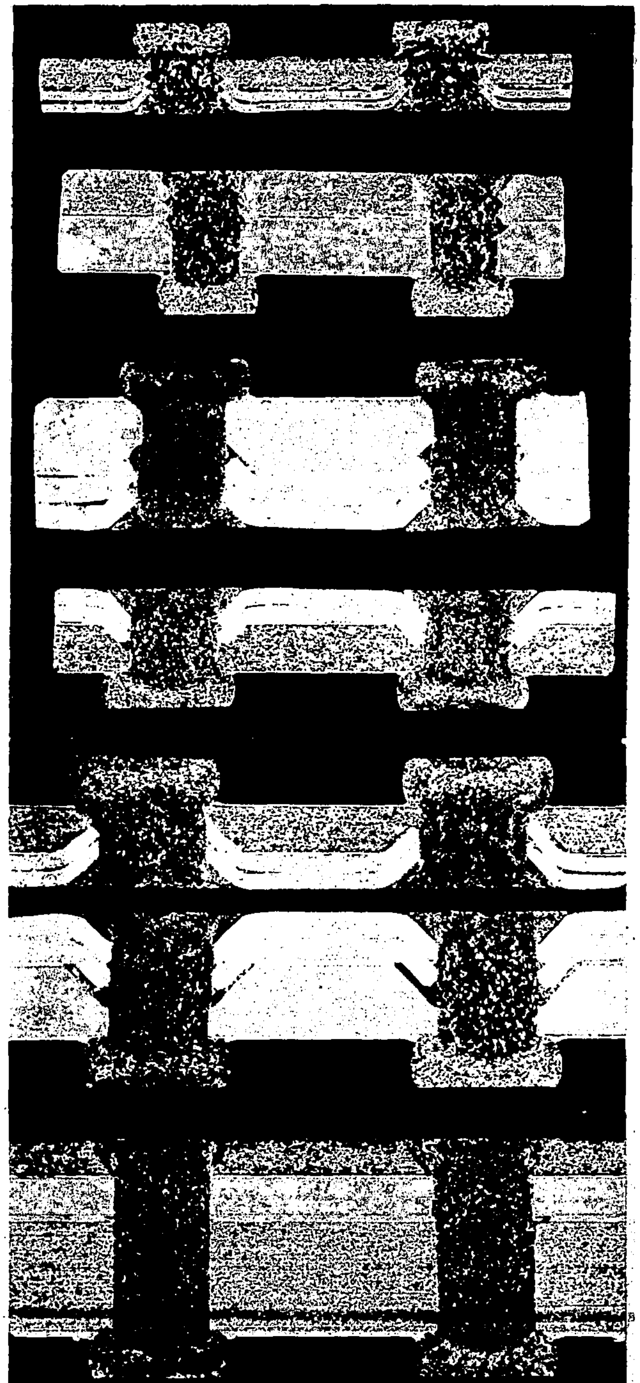


Figure 10. Cross section of specimens from report 2.



t in.	d in.
0.065	
.020	1/8
.020	
.040	
.040	1/8
.125	
.156	
.051	5/32
.051	
.032	
.032	5/32
.102	
.102	
.032	3/16
.032	
.051	3/16
.051	
.156	
.081	
.081	
	3/16
.250	

Figure 11. Cross section of additional specimens from report 2.

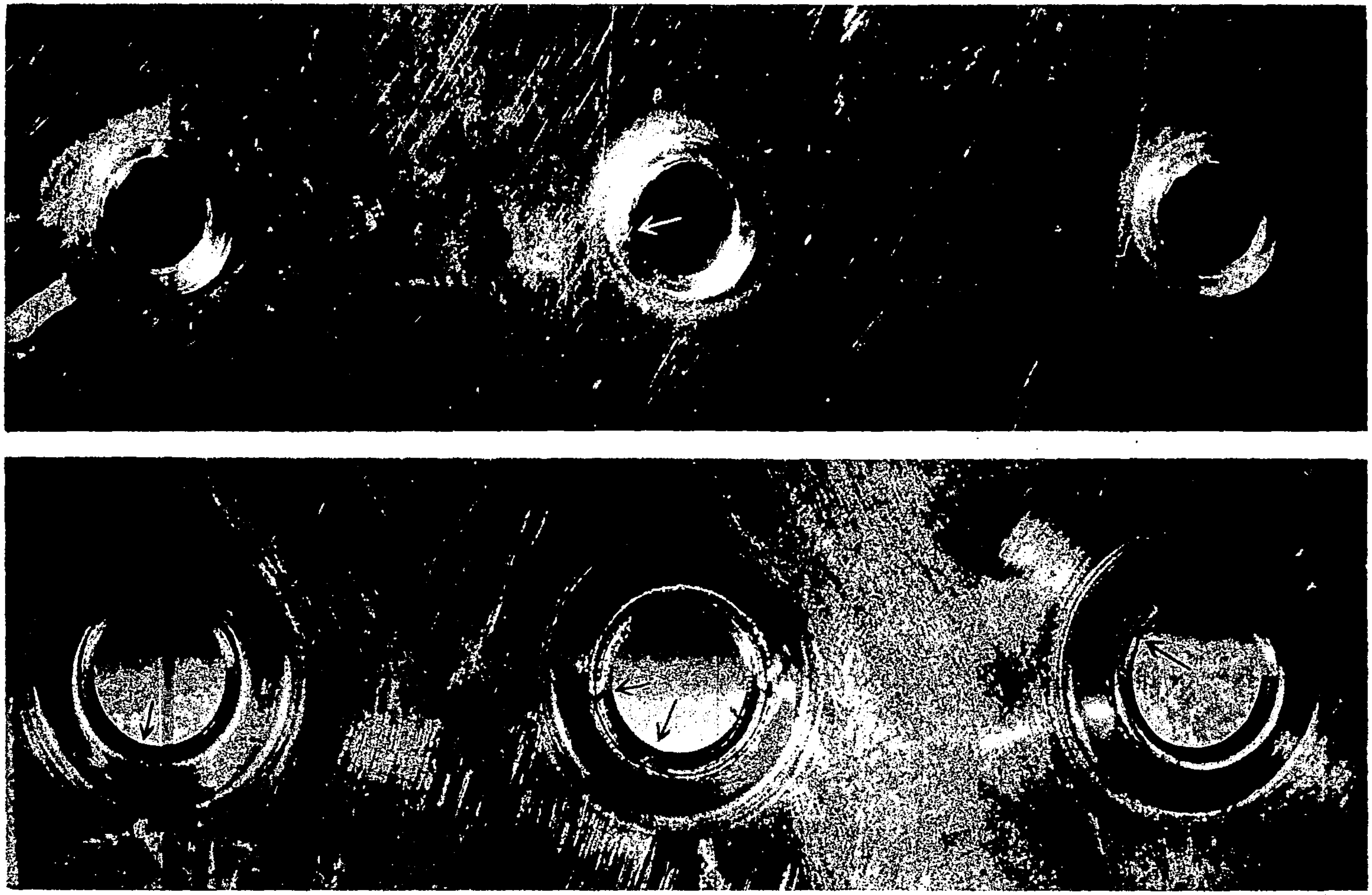
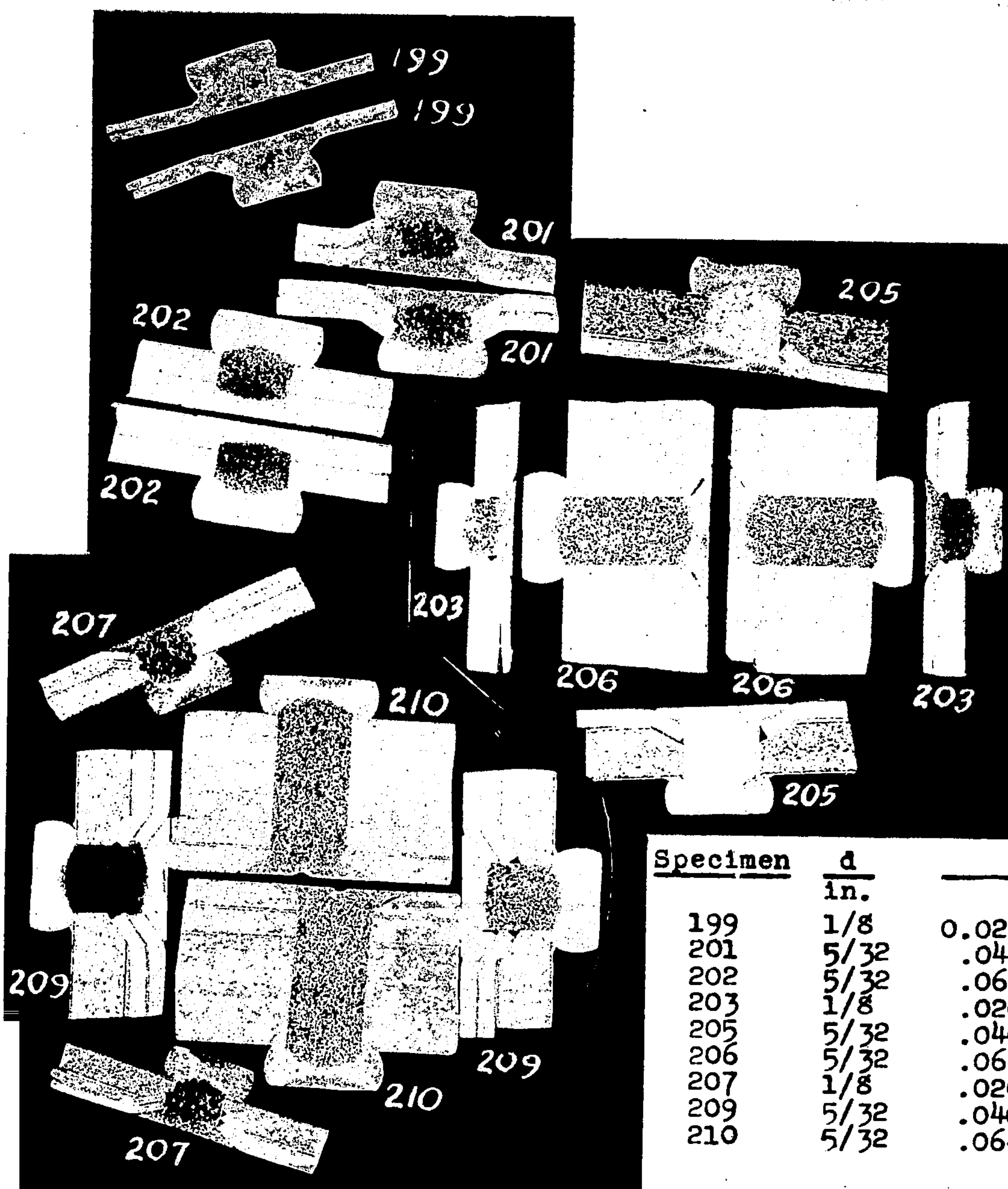


Figure 12. Radial cracks at dimples of specimens from report 2.

On top, specimen X; on bottom, specimen XI.

The sheets are those adjacent to the driven head.
Most of the cracks were smaller than the ones shown.



Specimen	d in.	t in.
199	1/8	0.020/.020
201	5/32	.040/.040
202	5/32	.064/.064
203	1/8	.020/.064
205	5/32	.040/.125
206	5/32	.064/.250
207	1/8	.020/.020/.064
209	5/32	.040/.040/.125
210	5/32	.064/.064/.250

Figure 13. Cross section of specimens from report 3.

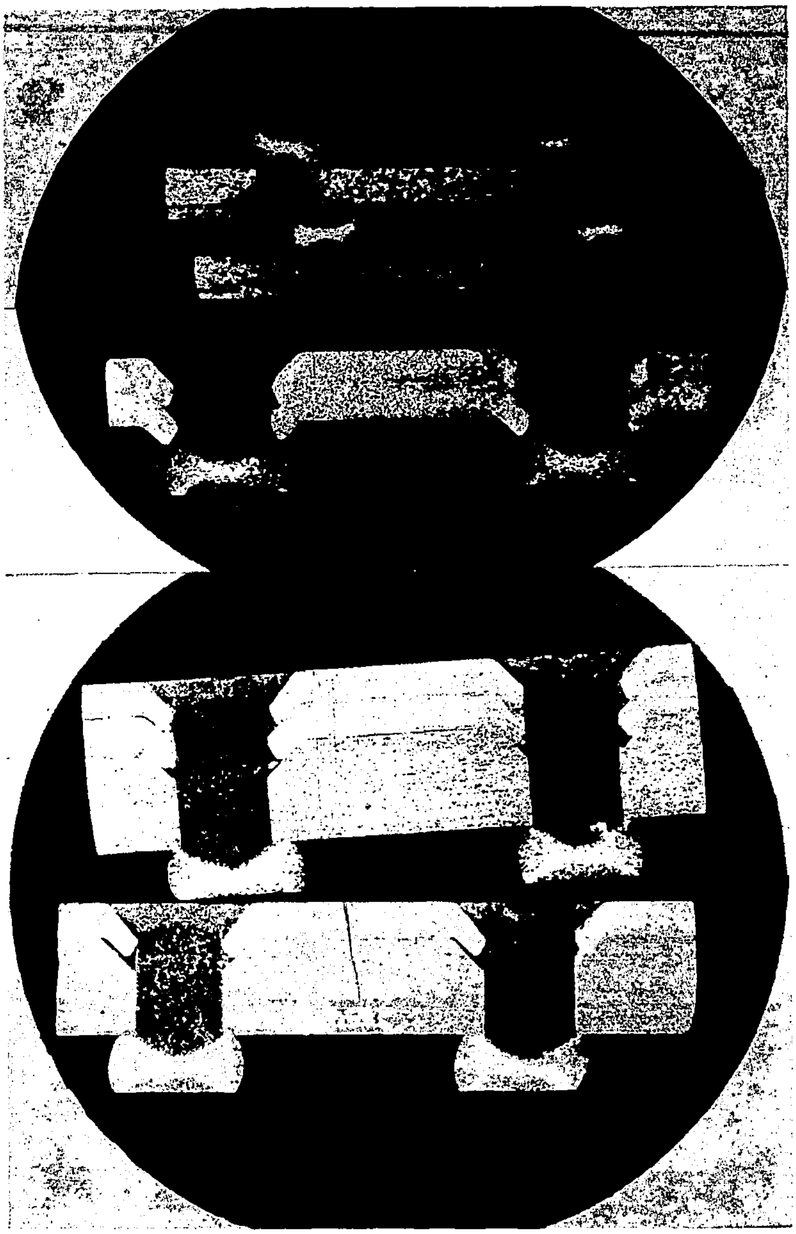
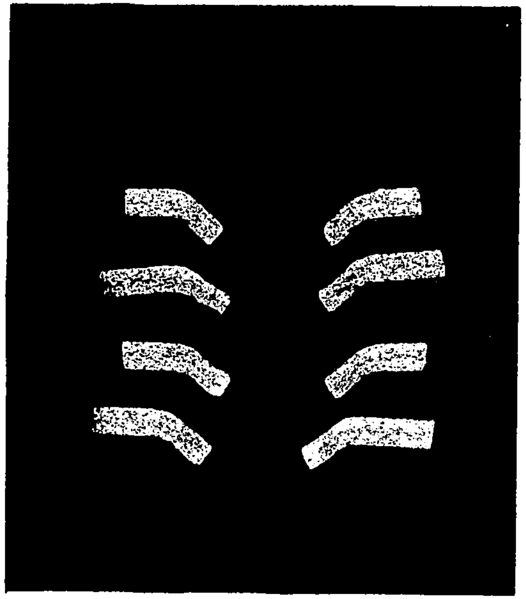
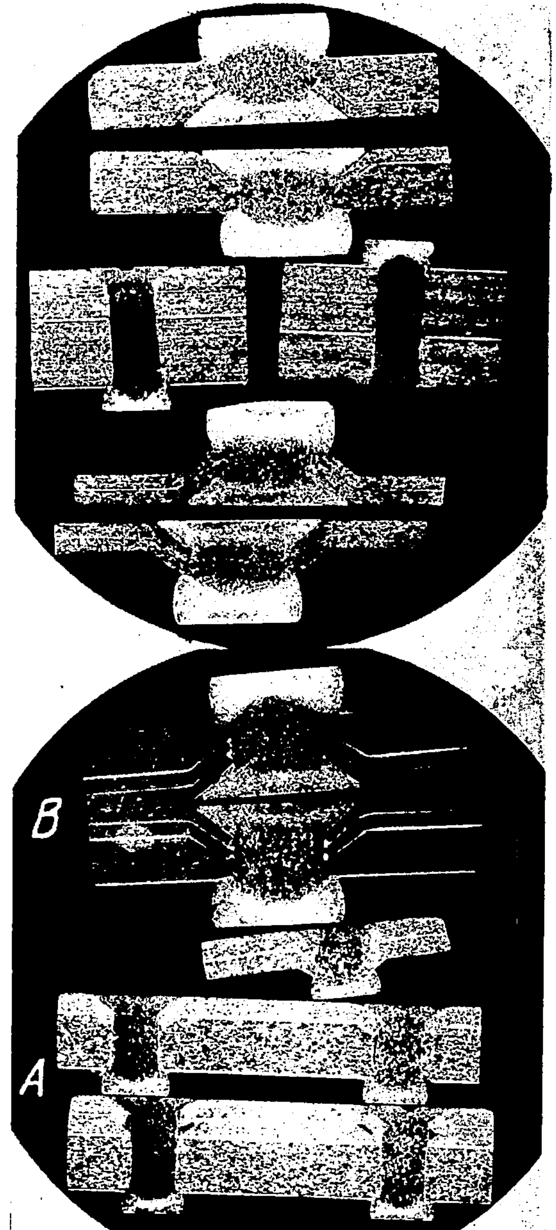


Figure 14. Cross section of specimens from report 4.





in.	in.
0.101 .032	3/16
.032 .101	3/16
.151 .051 .051	3/32
.032 .032	3/16
.032 .032	3/16
.101 .032 .032	3/16
.032 .032 .101	3/16
.040 .040	3/32
.040 .125	3/32
.040 .040 .125	3/32

Figure 15. Cross section of specimens from report 6. Construction A on right as distinguished from construction B was used for all dimpled type-IV specimens. Dimples from specimen XI are shown above.